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THE MAGAZINE OF THE EUROPEAN PHYSICAL SOCIETY

A tribute to J.J. Thomson

The first Solvay council on physics

Ernest Rutherford

Jan Czochralski

The moon as a detector

42/5
2011

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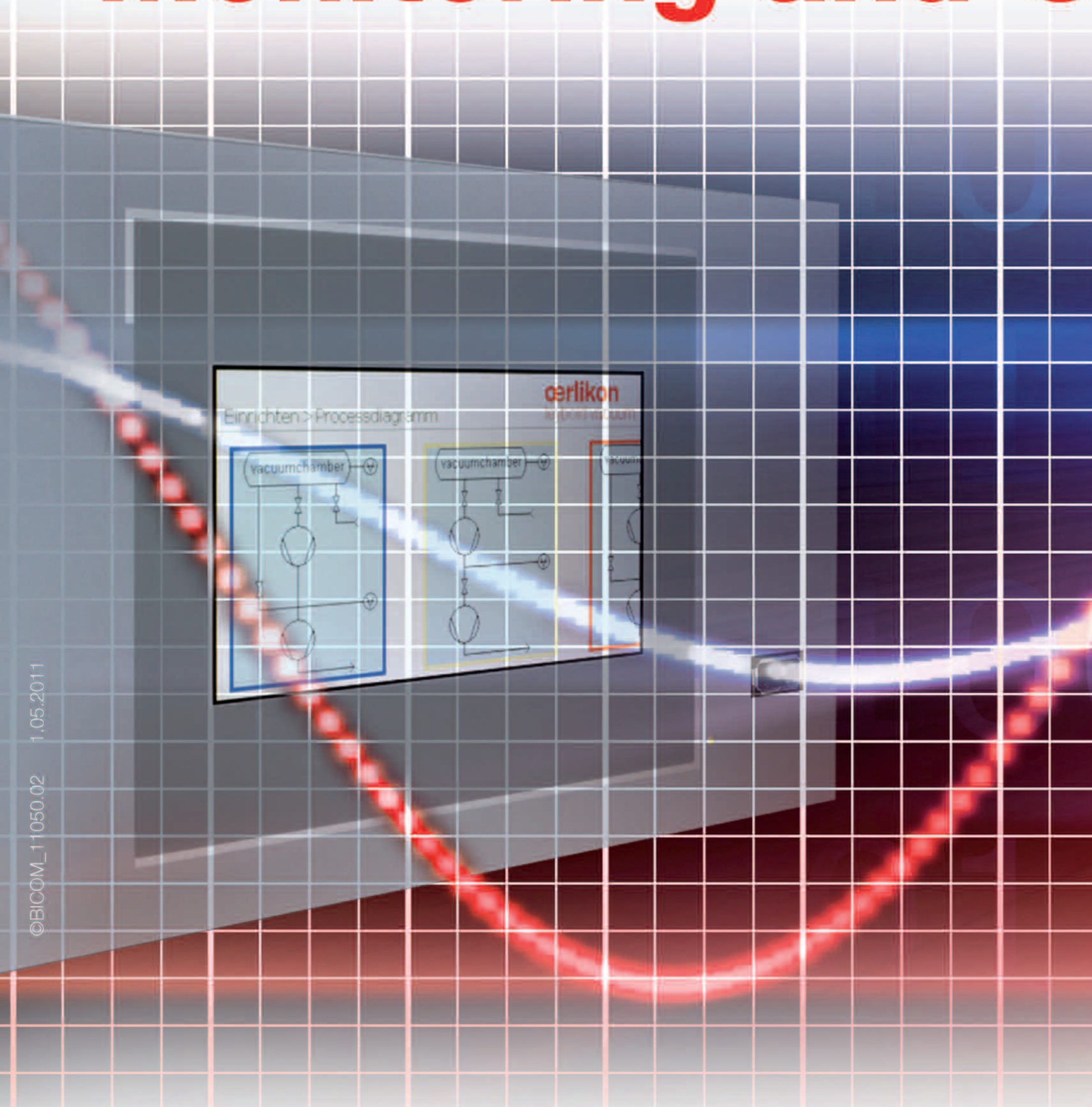

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Cover picture: Growth of a disodium zinc diphosphate single crystal using the Czochralski method. Such crystals are luminescent and serve as particle detectors or frequency doublers.
© CNRS Photothèque / Jannin François. See article on Jan Czochralski p. 22

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A tribute to J.J. Thomson

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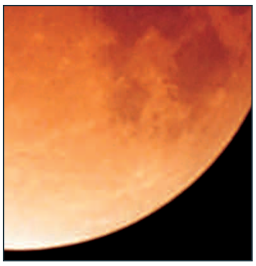
J. Czochralski, pioneer of crystal research



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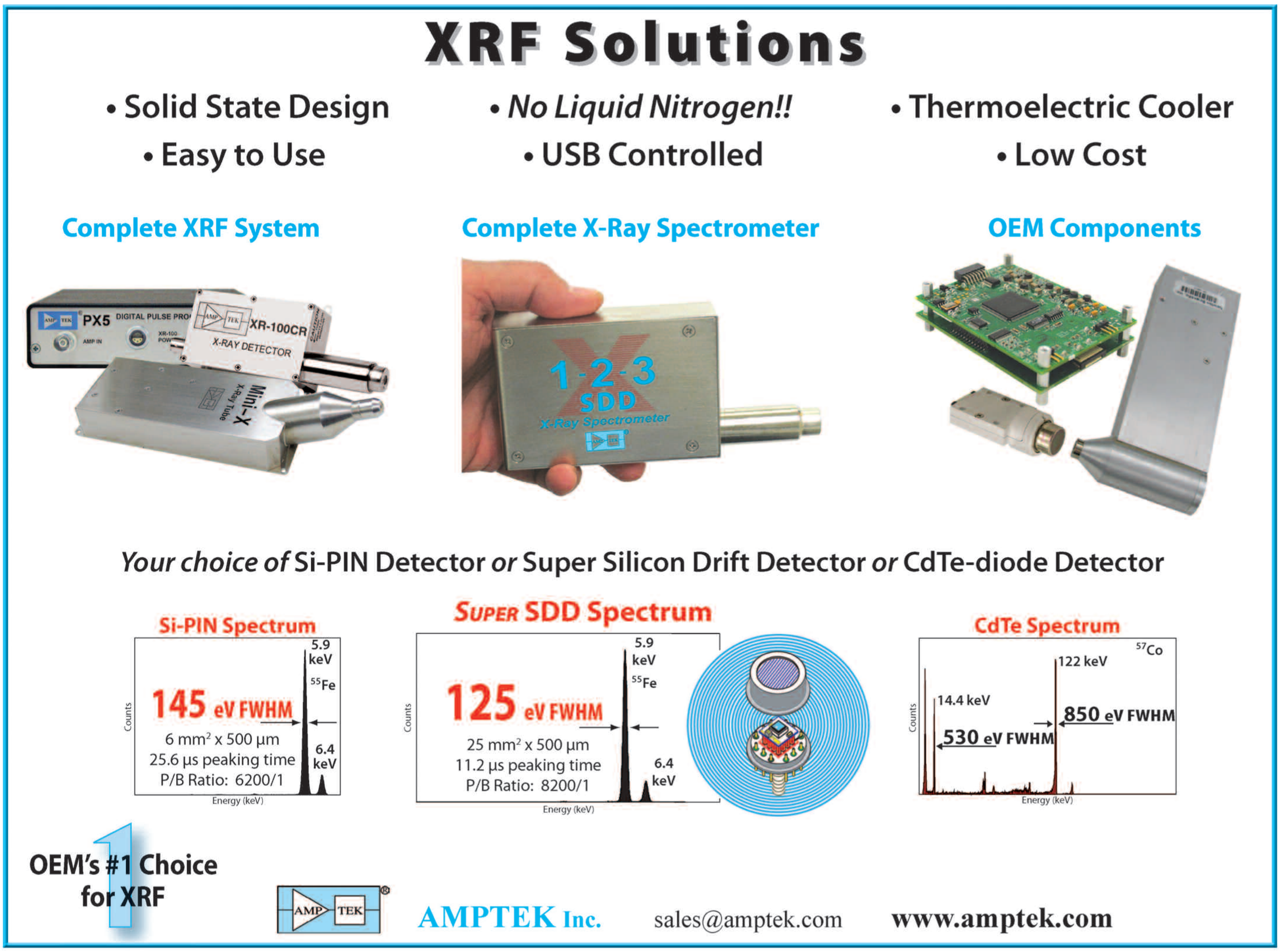
The moon as a detector of Ultra-High-Energy neutrinos



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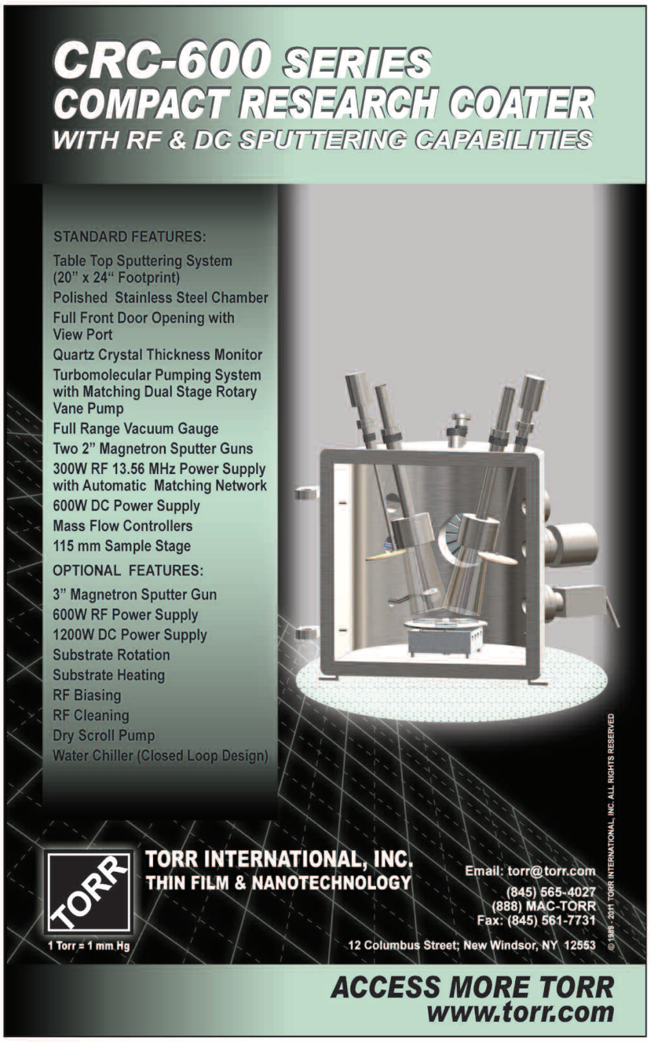

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A Year of Light: the EPS launch

The EPS-coordinated project, which requests the declaration of an International Year of Light in 2015, was formally launched during the joint EPS-SIF workshop *Passion for Light* on the 16 September. At the beautiful *Villa Monastero* – in Varenna, Italy – over a hundred distinguished physicists and guests participated in the announcement of the project's scope and goals, followed by a day long series of seminars covering all aspects of light.

Speakers included Nobel laureate, Theodor Haensch; quantum optics pioneer, Peter Knight; and the former Director General of CERN, Luciano Maiani. In addition, Mario Scalet, Head of the Science Unit of the UNESCO Venice office, described the general roles of UNESCO in supporting science, culture and education, while the Director of UNESCO's optics education programme, Joseph Niemela, provided an overview of the many outreach activities that UNESCO sponsors around the theme of light and its applications. Robert Kirby-Harris, Secretary General of International Union of Pure and Applied Physics (IUPAP), expressed the clear interest of IUPAP in this light initiative of the EPS.

By bringing together participants from so many different fields, *Passion for Light* showed very clearly how light impacts on all areas of science. The International Year of Light will aim to globally promote the fundamental understanding of light's importance more widely, focusing equally on issues of science, education and outreach.

The declaration of International Years can only be made by the United Nations General Assembly, and the EPS is now leading a large network of partners to work through the necessary administrative steps to declare 2015 the International Year of Light.

2015 is a natural choice, as it sees the convergence of a remarkable series of anniversaries in our understanding of light: 200 years since Fresnel's mémoire on diffraction introduced the notion of the wave nature of light; 150 years since Maxwell's work on electromagnetism paved the way for technologies from lasers to mobile phones; 100 years since Einstein and Hilbert established light and 'c' as an essential part of space and time, in the equations of General Relativity; and 50 years since Penzias and Wilson discovered the Cosmic Microwave Background, the electromagnetic echo of the Big Bang.

The first major step for the project is a formal request for endorsement from the General Assembly of the IUPAP in November. If all goes to plan, the next steps in 2012 and 2013 will involve wider discussions with scientific unions – equivalent to IUPAP – in other disciplines, and approaches to the UN via the UNESCO executive board.

In parallel, the EPS will continue to coordinate contact with national physical societies and other interested partners, and detailed planning for activities will begin. The general structure of the year-long activities has already been established, and will be focused around four broad themes, covering the fundamental science of light, the use of light as an enabling technology, the application of light to improve the quality of life in the developing world and an educational theme studying the pioneering scientists who have studied light and optics throughout history.

Light is a topic that cuts across science, technology, art and culture; and is the means by which humanity understands itself and the universe. The International Year of Light would be a tremendous opportunity to ensure the necessary global awareness of the importance of light – and the EPS, alongside the other invested partners, is putting its full support behind the project to ensure its success. ■

Luisa Cifarelli[1] and **John Dudley**[2],
[1] President of the EPS
[2] Secretary of the International Year of Light Project (light@eps.org)

Multispectral imaging in development

During the spring of 2011, while most attention was directed towards the various uprisings and the turmoil in several countries all over the African continent, the Malian TV evening news could bring something completely different on Monday 25th of April: The International Workshop on Applied Spectroscopy, Imaging and Multivariate Analysis held at Bamako University (Mali), 21st to 30th April, 2011.

The event was the latest in a row of recent activities organized by a pan African network for collaboration on the topic optical spectroscopy and multispectral imaging for application in health, agricultural and environmental sciences, sponsored by the International Science Programme, ISP-SIDA, Uppsala, Sweden. We organized the activity in continuation of a long tradition of our Lund University group on *Applied Molecular Spectroscopy and Remote Sensing* [1,2]. In our view, optics offers a good and cost effective way of getting hands-on experience on basic physical phenomena such as absorption and scattering, and at the same time apply the methods to every-day life problems. Pursuing a scientific career in the developing world can be exceptionally troublesome, but with a few examples on how spectroscopy and optics can improve crop outcome of nutmeg production, achieve improved malaria diagnostics or monitoring of agricultural pest, the motivation for increased support to the physics groups by their local communities could be substantially boosted.

▼ Calibration of the multispectral microscope constructed in University of Cape Coast, Ghana. From left: D.Linani (Kenya), A. Merdasa (Sweden), Prof. K. Kaduki (Kenya) and M. Brydegaard (Sweden).

The last few workshops have been oriented around the construction and calibration of a multispectral imager capable of acquiring images from UV to NIR in transmission, reflection and scattering mode [3]. The spectral bands are defined by inexpensive light emitting diodes rather than traditionally used costly gratings and filters. We have discovered a large synergy between developing realistic instrumentation in physics groups in the developing world and pursuing western world industrial innovation – in both cases the equipment has to be robust, simple and inexpensive in order to be interesting.

One of the golden rules from the Swedish funding agency, ISP, is that the initiative for activities should not come from Sweden, but from the receiving groups. One of the primus motors for establishing the African multispectral network has been Prof. Jeremie Zoueu, Ivory Coast. In his lab we have helped demonstrate how LED based imaging scattering spectroscopy can be used to map out malaria infected red blood cells without the use of time consuming staining.

This time the workshop in particular treated chemometrics and multivariate analysis, necessary to interpret complex multispectral image data and turn it into understandable scientific figures. Some of the subjects covered were singular value decomposition, multivariate regression, multidimensional histograms and construction of empirical dynamic models for processes like fruit oxidation or vegetation fluorescence. While a lot of attention was given to analyze data from our self-built multispectral microscopes, we also tried to emphasize the parallelism to the analysis of freely available multispectral satellite images, where the only difference is the pixel size.

Additionally, we brought two new aspects to the workshop this time: We introduced hands-on experiments on remote sensing methods including both passive reflectance measurements and actively remote laser-induced fluorescence. This could be achieved employing a low-cost amateur 8 inch reflective telescope and an inexpensive 405 nm violet 200mW laser pointer, recently developed. The remotely collected fluorescence recordings from vegetation are likely to be the first ones performed in Africa. The other new aspect was the introduction of a poster competition. It is important to make the workshops as interactive as possible, not only to hear instructors talking but to put demands of delivery on the participants. This year we arranged international groups of both students and seniors so that the several computer exercises and measurements would culminate in a poster presented the last day. The winning

▲ First African remote fluorescence measurements in Bamako, Mali; from upper left: M. Mbaye (Senegal), Dr. B. Anderson (Ghana), Prof. S. Svanberg (Sweden), H. Jayaweera (Sri Lanka), J. Opoku-Ansah (Ghana), Dr. A. Ndao (Senegal), A. Diakite (Mali), M. Sangare (Mali), Prof. J. Zoueu (Ivory Coast), Prof. K. Kaduki (Kenya).

team was found democratically excluding the possibility to vote for one self, and a prize of 100€ was given to each member of the winning team. The prize was sponsored by the European Physical Society Interdivisional Group of Physics for Development, IGPD-EPS.

As a doctoral candidate in Sweden you easily dig yourself deep into Matlab and find yourself wondering if anybody appreciates what you are trying to do. Likewise, as a professor you might sometimes doubt if your efforts have the impact that could motivate your many hours of overtime work. During the workshop in Bamako the engagement and enthusiasm swiftly washes away any such doubts. The participants had received reference articles, given out in advance, they were carefully read and underlined, and students together with seniors sad nailed to their chairs coding Matlab scripts twelve hours straight with the dedication as an aura surrounding them. The dean of the faculty, the minister of education and alphabetization, and the research minister joined us during the workshop. Even a single Ivorian made his way through crossfire with the escort of UN forces, for the obvious reason of attending the Multispectral imaging workshop in Bamako! Such events are not easily forgotten and for us it gives renewed confidence that what we do matters to somebody. ■

Mikkel Brydegaard and Sune Svanberg,
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and sune.svanberg@fysik.lth.se

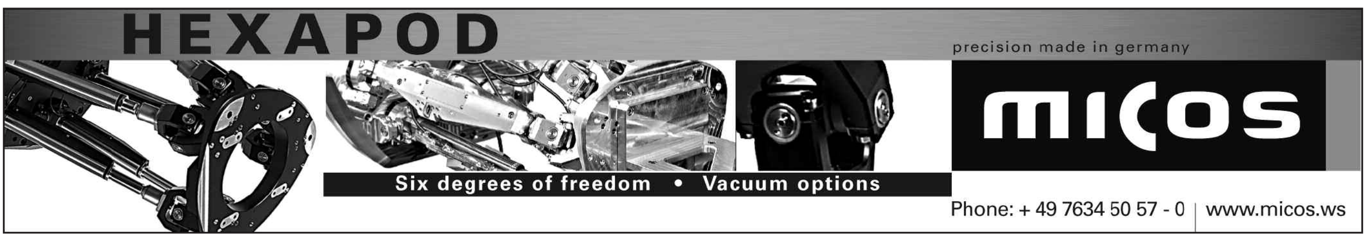
▼ Poster price winners and others, from left: Coordinator Prof. J. Zoueu (Ivory Coast), Dr. H. Kalambuka (Kenya), Dean Prof. A. Doucouré (Mali), S. Sylla (Senegal), the ISP sponsor Prof. E. v. Groningen (Sweden), A. Koulibaly (Senegal), the host Prof. A. Ba and co-organiser M. Brydegaard (Sweden/ Denmark).

References

[1] S. Svanberg, *Europhysics News* **33/2** (2002), 52

[2] K. Svanberg and S. Svanberg, *Europhysics News* **35/1** (2004)

[3] M. Brydegaard, A. Merdasa, H. Jayaweera, J. Ålebring and S. Svanberg, submitted to *Rev. Sci. Instr.* May 2011



Highlights from European journals

ASTROPHYSICS

The twin paradox in a cosmological context

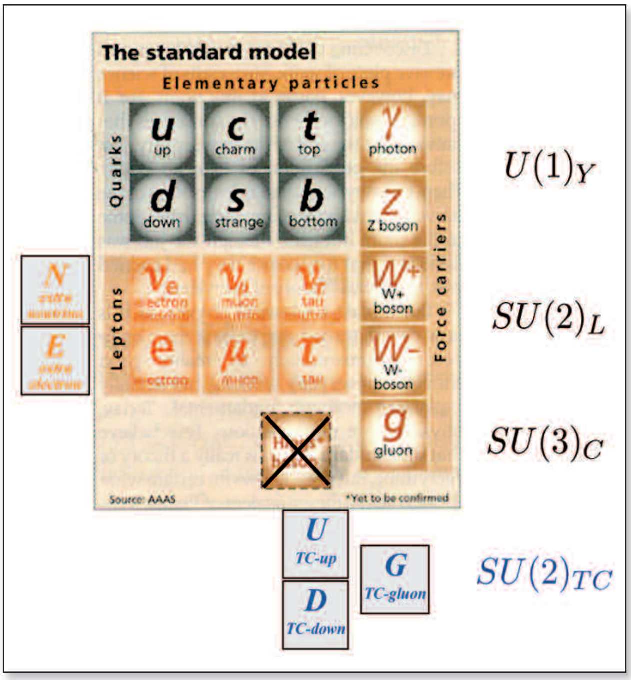
The twin paradox has been a source of debate since it was discovered by Einstein. It can be analytically verified assuming the existence of global nonrotating inertial frames.
The natural nonrotating frame and its identification with "fixed stars" is an aspect of Mach's Principle, which holds that the totality of matter in the universe determines the inertial frames.
Grøn and Braeck first note that the experiment by Hafele and Keating (1972), who flew atomic clocks eastward and westward around the Earth in commercial aircraft, also shows agreement with the expected result, assuming an inertial frame which is nonrotating with respect to "fixed stars." The authors then show that in the case of two observers in an otherwise empty universe (*i.e.*, without "fixed stars") moving at different speeds on a circular path yield different twin paradox results, depending on whether one or the other – or neither – observer is assumed to be at rest.
The authors ultimately take a fresh look at the work of Brill and Cohen, who studied the geometry inside a massive rotating shell, and conclude that in the black hole limit, such a mass distribution will drag the frames around at its own rotation rate.
Taken together, and given the entire universe closely satisfying the black hole condition, this paper lends further support to the Mach Principle. ■

Ø. Grøn and **S. Braeck**,
'The twin paradox in a cosmological context',
Eur. Phys. J. Plus **126**, 79 (2011)

PARTICLE PHYSICS

Discovering **Technicolor**

At present there are no known elementary scalar fields. A possible candidate is the as yet undiscovered Higgs particle; however it could well be that this elusive particle is instead composite. This possibility is exhaustively examined in this article, which is both tutorial and extensive review, classifying the diverse technicolor models as extensions of the Standard Model of particle physics. These model extensions are then compared with electroweak precision data, the spectrum of states common to most such models are identified, and their decays and associated



▲ Cartoon of the Minimal Walking Technicolor Model extension of the SM.

experimental signals for the LHC illustrated, including the implementation in event generators important for searches at the LHC. This timely review provides the most complete and up-to-date benchmarks for the potential discovery of technicolor models. ■

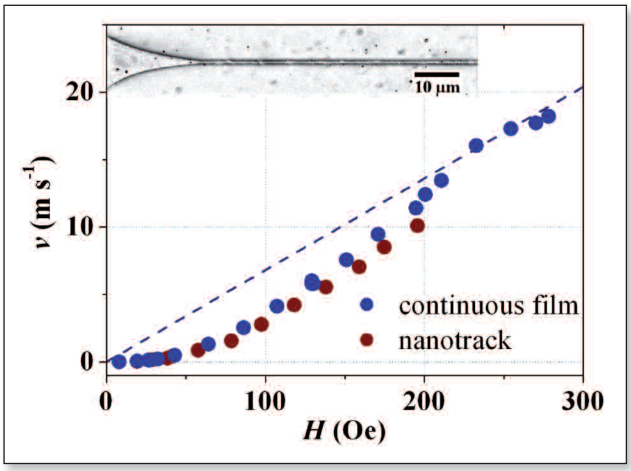
J.R. Andersen, **O. Antipin**, **G. Azuelos**, **L. Del Debbio**, **E. Del Nobile**, **S. Di Chiara**, **T. Hapola**, **M. Järvinen**, **P.J. Lowdon**, **Y. Maravin**, **I. Masina**, **M. Nardecchia**, **C. Pica** and **F. Sannino**,
'Discovering Technicolor', *Eur. Phys. J. Plus* **126**, 81 (2011)

MATERIAL SCIENCE

Fast domain-wall propagation in magnetic nanotracks

Magnetic domain walls are the interfaces separating magnetic domains of opposite magnetizations, which are used to store binary information in magnetic media. The current developments of magnetic data storage and processing technologies make highly desirable to control a fast and reproducible motion of these domain walls in nanoscale magnetic tracks. This can be performed using either magnetic field, or electrical current.
For this purpose, nanotracks defined in ultrathin magnetic films with out-of-plane magnetic anisotropy seem to be

particularly good candidates to obtain an efficient propagation under a low excitation. However, in most of the out-of-plane metallic nanosystems that were studied up to now, domain-wall pinning on the track's defects was shown to significantly reduce the domain-wall velocity, as compared to the one measured in the corresponding plain magnetic film.
In this work, nanotracks are etched in a Pt/Co/Pt thin film with out-of-plane magnetic anisotropy, where pinning has been artificially reduced by weak He^+-ion irradiation. It is shown that in these tracks, domain walls propagate as fast and under magnetic field as low as in the corresponding plain irradiated film.



▲ Domain-wall-propagation velocity, v, as a function of the applied magnetic field, H, in a plain Pt/Co/Pt film irradiated with He^+ ions, and in a 750 nm-wide nanotrack patterned in this film. The dotted line is a linear fit to the high-field velocity values in the film. Inset: Optical picture of a 510 nm-wide nanotrack.

Moreover, when magnetic-field and electrical-current pulses are simultaneously applied to the track, a considerably faster magnetization reversal is observed, which is due to a Joule-heating-induced thermomagnetic effect when current flows into the track. ■

▮▮▮ **M. Cormier**, **A. Mougin**, **J. Ferré**, **J.-P. Jamet**, **R. Weil**, **J. Fassbender**, **V. Baltz** and **B. Rodmacq**,
'Fast propagation of weakly pinned domain walls and current-assisted magnetization reversal in He^+-irradiated Pt/Co/Pt nanotracks', *J. Phys. D: Appl. Phys.* **44**, 215002 (2011)

QUANTUM PHYSICS

Controlling qubit arrays with anisotropic Heisenberg interaction

Quantum-control methods are employed to manipulate physical and chemical processes using time-dependent fields. In particular they can be used to develop quantum logic gates thus helping us achieve a major goal of modern physics, the realization of scalable quantum computation.

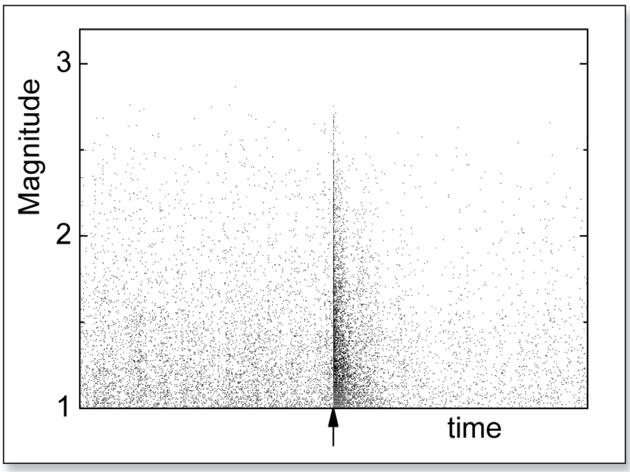
A large body of work in quantum control has been devoted to the study of interacting spin-1/2 chains since these are effective models of qubit arrays. While interactions between qubits are necessary for realizing entangling two-qubit gates, standard approaches for controlling such arrays by acting on each qubit do not make an explicit use of these interactions. However for some particular types of interaction it suffices to control only a small subsystem of a given system, the idea underpinning the local-control approach.
In this paper we have explored anisotropic Heisenberg interactions, relevant for the use of Josephson junction based superconducting charge-qubit arrays. This example is particularly interesting as the concept of local control can be taken to the extreme — controlling just one end qubit in an array. We investigated how time-dependent control fields acting on the first qubit in an array can be selected in order to realize relevant quantum logic operations (*e.g.* controlled-NOT, square-root-of-SWAP) in the shortest possible times.
Further extending the idea of local control, we showed that in building some quantum gates the degree of control over the chosen end qubit can be further reduced by acting with a control field in only one direction (say, x direction). Most remarkably, we demonstrated that in the parameter regime of interest for superconducting charge qubits this reduced control can lead to a more time-efficient realization of relevant gates than the approach involving alternate x and y control fields. We anticipate that our findings will facilitate implementations of quantum computation in superconducting qubit arrays. ■

▮▮▮ **R. Heule**, **C. Bruder**, **D. Burgarth**, and **V.M. Stojanovic**,
'Controlling qubit arrays with anisotropic XXZ Heisenberg interaction by acting on a single qubit', *Eur. Phys. J. D* **63**, 41 (2011)

GEOPHYSICS

Delayed dynamic triggering of earthquakes

In recent years, evidence has been accumulating that seismic waves generated by a large earthquake can produce additional quakes far away of the main shock. This may not be surprising when the secondary quakes occur right at the occurrence of the seismic waves. However, in general these dynamically triggered earthquakes occur hours or days after the main shock, namely when the seismic waves have elapsed.
In order to understand the origin of this phenomenon, we have adapted a recently proposed statistical model of seismicity that takes into account the existence of plastic relaxation processes within the faults. This kind of model has been used before to obtain realistic sequences of earthquakes, including in particular aftershocks. By appropriately defining a perturbation ▶



▲ Magnitude-time plot of quakes in the model. At the time of the arrow an instantaneous perturbation is applied. Note the resulting increase in activity.

(assumed to be the occurrence of seismic waves), it is observed that the seismic activity in the system has a sharp increase following the perturbation, well after it has vanished.

The origin of a temporarily delayed effect in the model is tightly related to the existence of relaxation processes, as the effect does not exist in the case in which relaxation is absent. In this respect delayed dynamically triggered earthquakes are in some sense similar to aftershocks: the latter are delayed events triggered by a permanent perturbation (the change in the stress field caused by the main shock) while the former are delayed events triggered by a transient perturbation (the passage of seismic waves), once the perturbation has vanished.

The present investigation suggests that both aftershocks and delayed dynamically triggered quakes originate in the same kind of physical mechanism, namely internal relaxation mechanisms within the faults, that the present model appropriately captures. ■

E.A. Jagla,
'Delayed dynamic triggering of earthquakes: Evidence from a statistical model of seismicity', *EPL* **93** 19001 (2011)

QUANTUM PHYSICS

Observing **different quantum trajectories** in cavity QED

Quantum systems, as isolated as they can be, always interact with their surrounding environment. This interaction can lead to correlations between system and environment and, when the states of the reservoir are inaccessible to observation, to an irreversible loss of information on the system. This deleterious decoherence effect is at the heart of the quantum theory of measurement and plays an essential role in explaining the emergence of classical behaviour in quantum systems.

However, this system-reservoir interaction can be exploited in a completely different way when the environment can be monitored. In this case, extracting information from the environment causes the state of the system to change stochastically, conditioned on the measurement record. This can then be used to manipulate the system dynamics, being an important strategy in quantum dynamical control.

While it is well known that there are infinitely many possible ways of unravelling the decoherence process in terms of stochastic trajectories, it is not always clear how to interpret these trajectories in terms of concrete physical measurements on the environment. In this paper we show how to produce, in a controllable manner, a variety of quantum trajectories in realistic cavity quantum electrodynamics setups. In the microwave regime, we show how the detection of atoms that have crossed a cavity can induce a jump in the field proportional to its quadrature. In this case, the field dynamics is quite different from the usual photodetection monitoring and can be used to produce conditional four-component cat-like states. Alternatively, in the optical domain, the detection of photons can be used to protect entangled states of atoms that have interacted with the cavity field.

This proposal for the implementation of new stochastic trajectories in terms of continuous measurements in realistic systems certainly expands the possibility of engineering quantum states of lights and atoms. ■

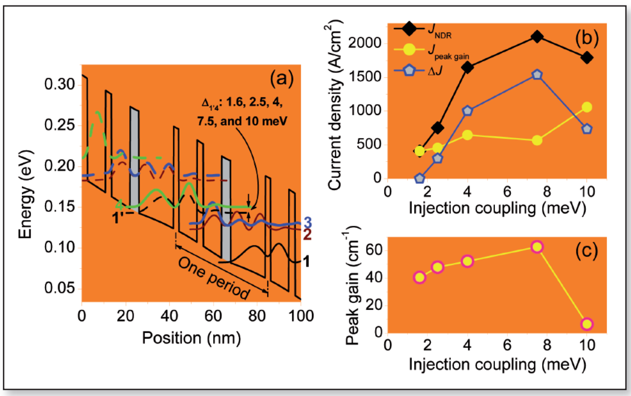
M.F. Santos and **A.R.R. Carvalho**,
'Observing different quantum trajectories in cavity QED',
EPL **94**, 64003 (2011)

MATERIAL SCIENCE

Injection coupling **in quantum-cascade lasers**

High-performance quantum-cascade lasers (QCLs) emitting at terahertz frequencies are highly expected for some practical applications, such as imaging and sensing.

▼ (a) Typical conduction band structure of terahertz QCLs investigated here. The injection coupling ($\Delta_{1'4}$) varies from 1.6 to 10 meV. The light grey regions represent doping layers. (b) Calculated J_{NDR}, $J_{peak\ gain}$ and ΔJ as a function of injection coupling. (c) Peak gain for different injection coupling structures.



Though mid-infrared QCLs operating in room temperature and continuous wave mode had been achieved, the wavelength extension to terahertz is pretty difficult due to the large free carrier absorption loss and small subband energy spacing. The performance improvements of terahertz QCLs need advances in active region and waveguide designs.

Recently the injection coupling parameter has attracted much interest because it not only affects the injection efficiency but also determines the laser gain shape and peak gain values. A density-matrix based calculation showed that a much stronger injection coupling (18 meV) should be employed for high performance mid-infrared QCL designs and the simulation has been verified by experiments.

Since the injection coupling plays an important role in the design and realization of high performance mid-infrared QCLs, it could also take effect in terahertz range. The research team investigated the effect of injection coupling strength on terahertz QCLs using an ensemble Monte Carlo method. An optimal injection coupling strength of 7.5 meV for dynamic lasing range and peak gain has been obtained for a 3.7-THz QCL. It is worth noting that the optimal injection coupling value is strongly dependent on the wavelength of the specific terahertz QCL design. ■

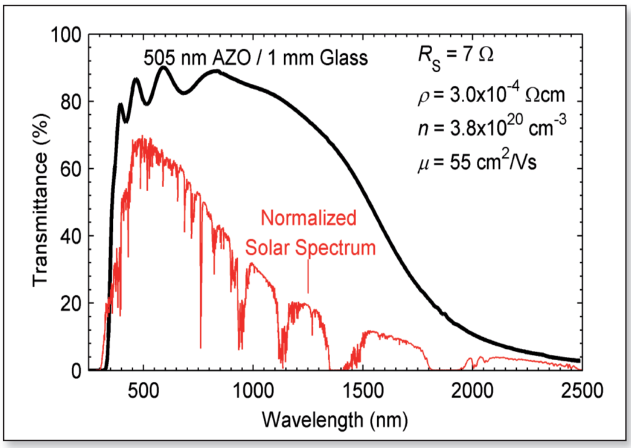
H. Li and **J.C. Cao**,
'Effect of injection coupling strength on terahertz quantum-cascade lasers', *Semicond. Sci. Technol.* **26**, 095029 (2011)

MATERIAL SCIENCE

Fast growth of high mobility ZnO:Al by cathodic arc deposition

Transparent conducting oxides (TCOs) are increasingly important materials as the demand for high efficiency solar cells, displays, and smart windows increases. Currently, indium tin oxide (ITO) is the preferred material for its properties of low resistance and high visible light transmittance. Excessive indium demand justifies the search for abundant and low cost alternative materials to satisfy the growing need of coating (>10^8 m^2/year). The best ZnO films doped with Ga or Al typically deposited at low rate by magnetron sputtering, are attractive but their performance is usually inferior to ITO.

Using a lesser known technique, called dc filtered cathodic arc deposition, we have shown that very high quality Al-doped ZnO (AZO) can be grown at rates 10 times higher than the rates for sputtering. Filtered cathodic arc produces a flux of fully ionized material, in stark contrast to sputtering which occurs at much lower power and predominantly produces a flux of neutral atoms. The arc-produced ions bring significant potential and kinetic energies to the surface, which leads to heating of the growing film just where the growth occurs while the substrate as a whole can remain at a much lower temperature. If the ion flux is high, the surface heat accumulates and anneals the film as it grows. The result is high quality AZO with electron mobility approaching the theoretical limit for polycrystalline AZO films. High electron mobility is what allows TCOs to transmit light throughout the solar spectrum while maintaining high conductivity since the electron concentration does not have to be very high. ■



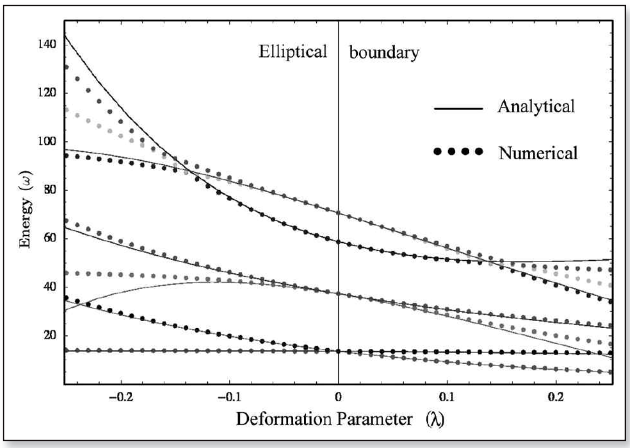
▲ Transmittance of a 505 nm thick AZO film on 1 mm thick float glass showing a sheet resistance of 7 Ω with a carrier mobility of 55 cm^2/Vs, a very high value for doped ZnO on glass. The film is transparent not only in the visible but for most of the solar spectrum, which is also shown.

R.J. Mendelsberg, **S.H.N. Lim**, **Y.K. Zhu**, **J Wallig**, **D.J. Milliron** and **A. Anders**,
'Achieving high mobility ZnO:Al at very high growth rates by dc filtered cathodic arc deposition', *J. Phys. D: Appl. Phys.* **44**, 232003 (2011)

OPTICS

Eigenvalue problem in 2D for an irregular boundary

The Helmholtz equation arises in a number of physical contexts as one reduces the wave equation by considering single frequency propagation. One such application appears in studying wave behaviour in waveguides. While waveguides in technology are carefully engineered to have, for instance, constant and simple cross-sectional geometries, natural waveguides relax such engineering constraints. (Natural waveguides range across systems from atmospheric and oceanic ducts, to biological systems such as seal and polar bear hair fibres.) In particular the cross section of natural waveguides tends to have a complex boundary shape that is far from the ideal circular or rectangular form of engineered waveguides.



▲ Comparison of the eigenvalues obtained numerically and analytically for an elliptical boundary (in units of $1/R_0^2$) with Neumann condition for the first 7 states.

The present team proposes a new approach to the irregular boundary 2-d Helmholtz equation with Neumann boundary conditions (specified normal derivatives of the field at the boundary). This boundary condition has significant physical importance: it is the natural one for electromagnetic propagation in the TM mode in waveguides.

To date the most successful efforts to solve the irregular boundary Helmholtz equation have been computational, but even this general method has its drawbacks. The present analytic perturbative approach solves the irregular boundary problem via a perturbative series. The authors explicitly work out several nontrivial examples. The benefits of this approach include, most importantly, an analytical understanding of the behaviour of the solution as the amplitude of the boundary distortion is increased.

Another important feature of *Panda et al.'s* expression is its analytic precision in the terms computed and its analytic error estimates for the terms truncated from the series. Together these give the analytic methods a much larger dynamic range than available computationally. ■

S. Panda, **S. Chakraborty**, and **S.P. Khastgir**, 'Eigenvalue problem in two dimensions for an irregular boundary: Neumann condition', *Eur. Phys. J. Plus* **126**, 62 (2011)

ATOMIC AND MOLECULAR PHYSICS

XUV-FEL spectroscopy: He two-photon ionization cross-sections

Non-linear optical processes of atoms and molecules such as multiphoton absorption and tunnelling ionization are very attractive issues in current atomic, molecular and optical sciences. The recent development of free electron laser (FEL) sources enabled us to investigate such non-linear optical processes in the extreme ultraviolet (XUV) wavelength regions Our group demonstrated that we can determine absolute values of a two-photon ionization cross section of atomic species and its wavelength dependence by using an XUV FEL light source. This was achieved by introducing an internal reference for the cross section measurements and by the frequency tunability of the FEL light source.

The FEL light source we used is the SPring-8 Compact SASE Source test accelerator in RIKEN, Harima Institute, equipped with a couple of compact vacuum undulators, having a unique advantage of its high peak intensity and frequency tunability in the 50 ~ 62 nm region.

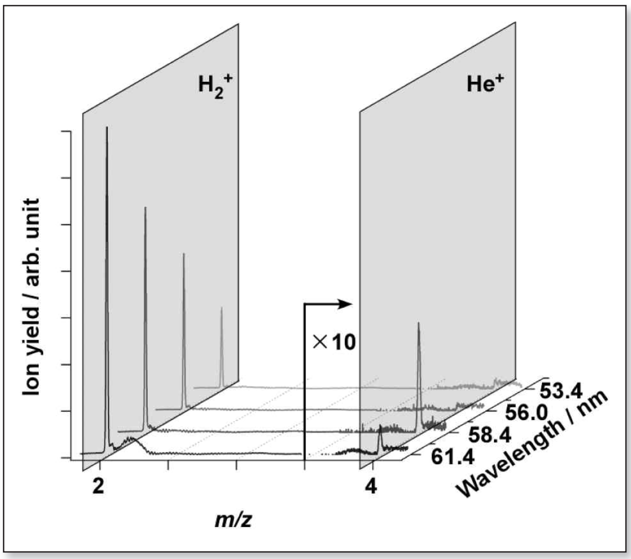
We measured the wavelength dependence and the light field intensity dependence of the absolute values of two-photon ionization cross section of He at 53.4, 58.4, 56.0 and 61.4 nm, covering the 1s2p and 1s3p resonances in the light field intensities range of 5×10^{12} ~ 5×10^{13} W/cm^2 by measuring simultaneously one-photon ionization signal of H_2 mixed in the sample as reference.

We showed through the critical comparison with the theoretically obtained cross sections that, in the resonance wavelength regions, dressed state formation through the strong coupling between the intermediate 1snp resonance state and the $1s^2$ ground state needs to be taken into account if the XUV light field intensity becomes larger than ~10^{12} W/cm^2.

We are now entering into the stage of quantitative non-linear spectroscopy in the XUV wavelength region. ■

T. Sato, **A. Iwasaki**, **I. Kazuki**, **T. Okino**, **K. Yamanouchi**, **J. Adachi**, **A. Yagishita**, **H. Yazawa**, **F. Kannari**, **M. Aoyma**, **K. Yamakawa**, **K. Midorikawa**, **H. Nakano**, **M. Yabashi**, **M. Nagasono**, **A. Higashiya** and **T. Ishikawa**, 'Determination of absolute two-photon ionization cross section of He by XUV Free Electron Laser', *J. Phys. B: At. Mol. Opt. Phys.* **44**, 161001 (2011)

▼ The time-of-flight mass spectra of He^+ and H_2^+ recorded at λ = 61.4, 58.4, 56.0 and 53.4 nm.



CONDENSED MATTER

Electromagnetic force density and energy-momentum tensor **in any continuous medium**

For more than a century, physicists have searched for a unique and general form for the force density that an electromagnetic field imposes on a medium. The existing expressions for this quantity, obtained, *e.g.*, by Minkowski, Einstein and Laub, Abraham, and Helmholtz, are different, and, as such, give different predictions in particular physical situations. The theories of Abraham and Minkowski, for example, ignore the existence of electro- and magnetostriction. Moreover, real media with dispersion, dissipation, and nonlinearities have not been addressed much.

We present an unambiguous general equation for the electromagnetic force density $f = -\nabla\cdot T - (dG/dt)$ expressed in terms of a new three-dimensional energy-momentum tensor T and momentum density G of the field. The tensor T can be written as $T = T_M + I_V$, where T_M is the Minkowski tensor, I the unit tensor, and *V* the density of the field-matter interaction potential that is responsible for electro- and magnetostriction. Remarkably, if the medium is not magnetic, the momentum density G is given by Abraham's expression $G = E\times H/c^2$. If the material obeys the Clausius-Mossotti law, the tensor T becomes the Helmholtz tensor that to our knowledge has not been contradicted in any experiment so far.

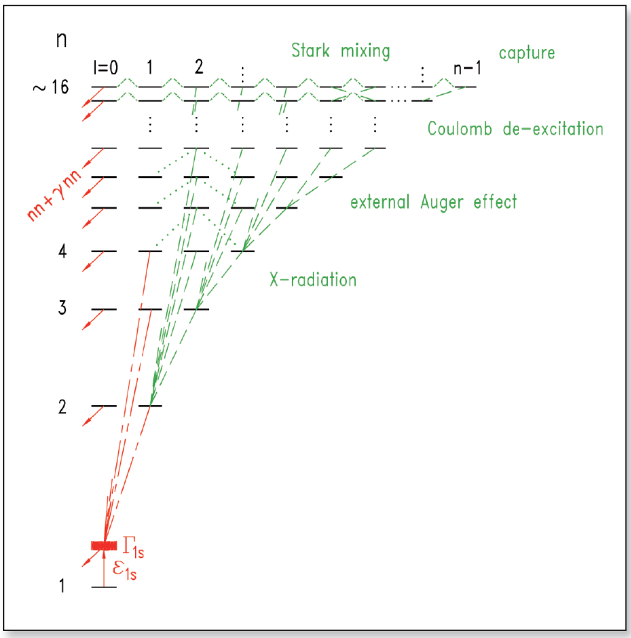
The general equation obtained for the force density can be applied to essentially any natural or designed material whether inhomogeneous, anisotropic, nonlinear, dispersive, or dissipative, and even to materials providing optical gain. We also calculate the rate of work done on a medium by an electromagnetic field, and using the result, obtain the four-dimensional energy-momentum tensor T_4 in spacetime. Interestingly, this tensor is physically very close to the almost forgotten tensor of Einstein and Laub. ■

A. Shevchenko and **M. Kaivola**,
'Electromagnetic force density and energy–momentum tensor in an arbitrary continuous medium', *J. Phys. B: At. Mol. Opt. Phys.* **44**, 175401 (2011)

PARTICLE PHYSICS

Pionic Deuterium

A new precise measurement of the pD(3p–1s) X-ray transition in the pionic deuterium atom has been performed at the PSI accelerator in Switzerland. The pionic deuterium is a short lifetime atom, where the negative pion (p^-) replaces the electron, resulting in an atomic size scaled down by the ratio of the pion mass over electron mass, a factor of about 270.



▲ De-excitation cascade in pionic deuterium.

The experiment makes use of a high intensity decelerated beam of p^- stopping in a cooled deuterium gas target where the p^- is captured. Following the capture an atomic de-excitation quantum cascade of 0.1ns duration takes place and the atom ends up in the 1s ground state as shown in the Figure. A Bragg spectrometer equipped with a bent Silicon crystal and pixel semiconductor detectors provides the precise X-ray detection in the appropriate keV region.

The measurement of the energy of the X-ray emitted in the pD(3p–1s) transition leads to a new value of 3075.583 ± 0.030 eV. A new and updated calculation of this transition energy assuming a pure electromagnetic system (pure QED - no strong interaction) leads to a value of 3077.939 ± 0.008 eV. The difference between these two quantities gives exactly the hadronic shift $e_{1s} = -2.336 \pm 0.031$ eV. The line-shape has been analysed, providing a new and precise value of the hadronic broadening G_{1s} = 1.171+0.023 -0.049 eV.

The accuracy of 1.3% achieved for the shift e1s leads to a more precise determination of the isoscalar scattering length a^+ (pD being an isoscaler object). The new precise value obtained for the hadronic broadening G_{1s} leads to a new determination of the threshold parameter a, the transition strenght for a S-wave pion, with unprecedented accuracy. ■

Th. Strauch, **F.D. Amaro**, **D.F. Anagnostopoulos**, **P. BÅ-Nuhler**, **D.S. Covita**, **H. Gorke**, **D. Gotta**, **A. Gruber**, **A. Hirtl**, **P. Indelicato**, **E.-O. Le Bigot**, **M. Nekipelov**, **J.M.F. dos Santos**, **Ph. Schmid**, **S. Schlesser**, **L.M. Simons**, **M. Trassinelli**, **J.F.C.A. Veloso** and **J. Zmeskal**,
'Pionic Deuterium', *Eur. Phys. J. A* **47**, 88 (2011)

A tribute to J.J. Thomson

■ Henk Kubbinga - University of Groningen (The Netherlands) - DOI: 10.1051/epn/2011501

Europe was thrilled by a new instrument, or was it just a gadget? The gas discharge tube was invented by Johann Geissler (1857). Very soon it became a British plaything: with his demonstrations William Crookes impressed the Royal Society (1878) and the British Association for the Advancement of Science (1879). The new Cavendish Professor for Experimental Physics, at Cambridge, Joseph John Thomson —simply J.J. for colleagues and posterity—took over.

Born near Manchester to a bookseller-antiquarian in 1856, Joseph John Thomson was expected to become an engineer. However, at Owens College, Manchester, his attention after a while shifted to mathematics. The shift was a conscious one, since mathematics was the only way to get an endowed entrance at Cambridge, more particularly at Trinity College. In 1880, then, Thomson passed the final examination, second in line, after Joseph Larmor. Through his *Treatise on Electricity and Magnetism*, Clerk Maxwell, whose tragic death was still in the air, reigned supreme, together with Stokes and the future Lord Kelvin. Physics still was essentially *mathematical* physics. In this context a prize-winning essay by Thomson was published as *A Treatise on the Motion of Vortex Rings* (1883). In it he inter alia described, following his distinguished namesake, several experiments with magnetized needles carried by cork slices on top of a water surface, grouping around a large magnet's pole at the centre. Other topics that occupied Thomson derived from Maxwell's work: the nature of potential energy in mechanics and its relation to the kinetic energy of systems, and electrodynamics. In both, the use of mechanical models—to lead both the imagination and the mathematical analysis—was of paramount importance.

▼ FIG. 1: J. J. Thomson (painting in oils on canvas by Arthur Hacker, 1903; actually in the Common Room of the Cavendish Lab.).

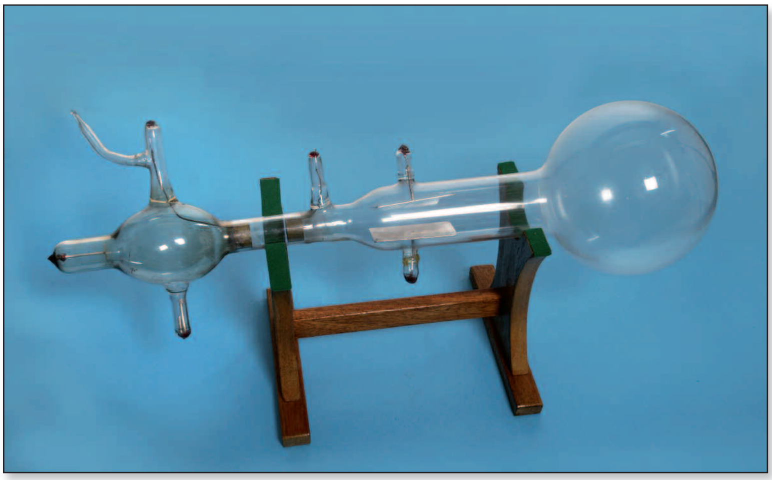
Through a series of fortunate coincidences, Thomson became short-listed when, in 1884, Rayleigh, the successor of Maxwell, moved on to the Royal Institution, London. He was nominated indeed and from the very outset, the discharge tubes with their fairy-like phenomena became his favourite research subject.

Discharge tubes; corpuscles

In the late 1850's the instrument-maker Johann Geissler of Bonn University, already a celebrity for his thermometers and his air pumps based on mercury, had equipped an evacuated tube with platinum electrodes. With the help of a recent invention, the Rühmkorff-inductor, he produced rapid successions of sparks through rarefied air and other gases. The set-up resembled Michael Faraday's when he studied the conductivity of various media. Hence the idea that it was a matter of electrolysis, this time of gases and accompanied by fascinating light effects that could be steered by a magnet. In 1875, a new invention—this time one by William Crookes, London—brought the discharge tube back into focus. The apparatus in question became known as the radiometer; it consisted of an evacuated bulb with a set of vanes, mounted on a spindle, which started to spin as soon as it was exposed to light. The experiment suggested that external light could have a mechanical effect, perhaps mediated by rest-gas molecules. The surface of the cathode of the discharge tube, then, could be likened to the black sides of the vanes: in both cases it would be a matter of bouncing molecules. Gradually, however, the ever more appealing discharge tubes took the place of the radiometer. Crookes postulated a fourth—extremely rare—state of matter, in which charged molecules could manifest their mechanical power. In one of his contrivances, a wheel with spades started spinning along a railway in the direction of the anode, even braving gravity when kept slightly inclined: obvious mechanics, matter in motion driven by matter in motion.

Evacuated tubes with aluminium foil windows showed Heinrich Hertz (1892) that cathode rays could permeate such foils, a fact that stressed, from the British point of view, the tiny nature of the particles involved. How else might their free paths of some 5 mm in air be explained? Wilhelm Röntgen (Munich), in the autumn of 1895, noticed a secondary effect: the unexpected lighting up of remote fluorescent materials. Hendrik Lorentz (Leyden), then, made use of tiny particles—by now evidently *subatomic* moieties—to explain the broadening of the NaD-line between the pole pieces of a strong electromagnet, as discovered by Zeeman (October 1896).

Cambridge—with Oxford living in splendid isolation, even in the UK—had been opened, in 1895, to the academic world at large and advanced students looking forward to do research flocked to the Cavendish Laboratory. Before long, the PhD system was introduced in order to create 'research doctors', as in the German and French academia. Among the first to be admitted was one Ernest Rutherford, from New Zealand; many would follow. With Hertz's stunning find as inspiration, Thomson set out to study both charge and mass of the 'electrified particles' that constituted the cathode rays. In a first attempt, he established their kinetic energy by measuring their heat effect on a copper-iron "thermoelectric couple", connected to a sensitive galvanometer: $n \cdot (\frac{1}{2} mv^2) = W$ = kinetic energy of n particles transformed into heat with $n \cdot e = Q$ = quantity of electricity involved. A magnetic field of strength H causes the 'electrified particles' to adopt a circular trajectory of radius r. That radius varies, naturally, directly as the particle's mass m and its velocity v, and inversely as the particle's charge e and the magnetic field strength H. Hence $mv/e = Hr$, or $mv = eHr$, which may be substituted in the expression for W and leads to $m/e = \frac{1}{2} (Hr)^2 \cdot (Q/W)$. The ratio W/Q was measured first ($= 8{,}7 \cdot 10^{11}$ e.s.u.);



▲ **FIG. 2:** Thomson's (presumably original) discharge tube (length: 40 cm; cross-section bulb: 11 cm). The pierced anode(s), on the left, are in brass, the cathode and the condenser plates in aluminium; the latters' positions have suffered. The electrode on the lower-left was probably used to check the vacuum quality. Photo: Kelvin Fagan, Cavendish Laboratory.

r was calculated, next, from the path in the tube, a circle segment; H was the known strength of the electromagnet. By varying H and measuring r, Thomson established the product Hr (= 287 e.s.u.). Therefore $m/e = \frac{1}{2} \cdot (287)^2 / 8{,}7 \cdot 10^{11} = 4{,}7 \cdot 10^{-8}$ e.s.u. In a later experiment, which became a classic, Thomson combined the deviation in a magnetic field with that in an electric field. This led to $m/e = 1{,}2 \cdot 10^{-7}$ e.s.u. Again, hydrogen and carbon dioxide tubes gave the same results, while the metal of the cathode (Al, Pt) did not matter, so there were really fundamental particles at stake; From electrolysis data, the ratio m/e of hydrogen ions was already known to be 10^{-4}. Assuming the charges involved to be equal, Thomson's 'electrified particles' had to be some 1000 times lighter. His experiments thus confirmed the earlier results, as to the tiny nature of those particles.

The combined effect of magnetic and electric fields appeared to be the most practical way. The quality of the vacuum, then, proved essential: to confirm that there was indeed an *electric* field effect—that is, without conduction—the rest pressure had to be lowered further significantly. Figure 2 shows Thomson's well-known tube. The tube in question was blown—by Ebeneezer Everett, Thomson's cherished virtuoso [2]—from soft glass imported from Germany, known already for its lightgreen fluorescence when exposed to cathode rays. The logic was incontrovertible, the calculation refreshingly simple and straight forward.

Corpuscular matter

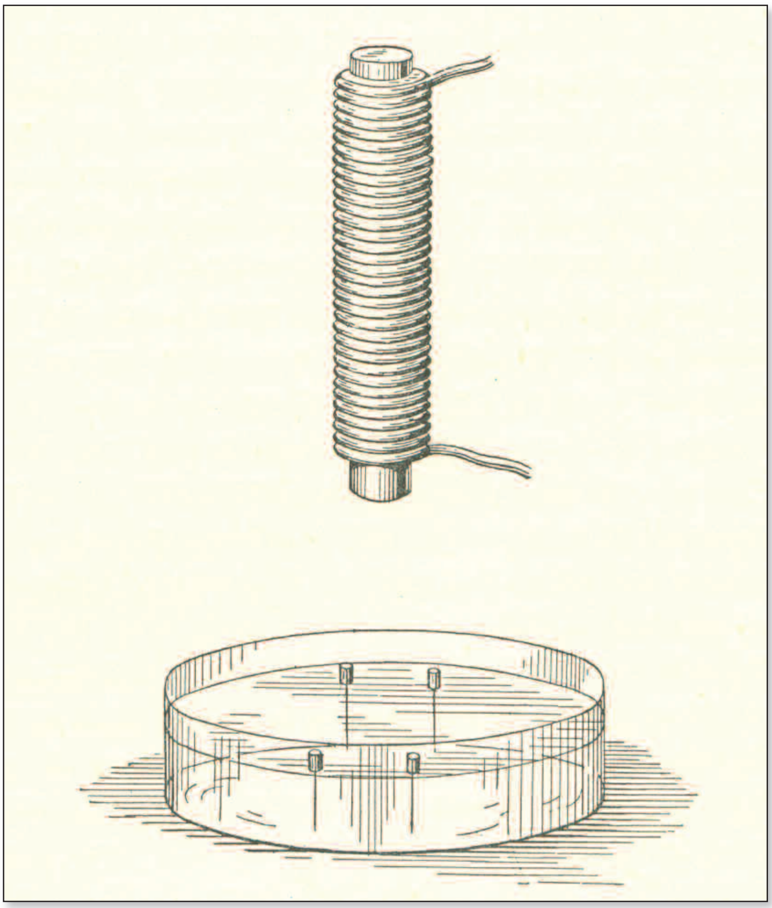
Thomson became convinced of the elementary nature of his *corpuscles*. Though most physicists gradually adopted the term 'electron'—proposed by Stoney in 1894—, Thomson did not give in for at least a decade. Indeed, the term corpuscle seemed consecrated by Thomson's being awarded the Nobel Prize of 1906. The next year, the laureate published his magnum opus, entitled *The corpuscular theory of matter*. As to terminology, apart from some stubbornness, there might be some piety in the game, scientific piety, that is: after all, ►

no one less than Robert Boyle had ventured to propose, in his days, a 'corpuscular philosophy' of similar stature (1661). For Thomson, then, the physico-chemical atom consisted of equal amounts of positive and negative electricity. The positive electricity was considered as a "sphere of uniform density" in which the *corpuscles* were embedded, like the raisins in a plumpudding. His earlier study of the ordering of corked magnetic needles, was helpful to visualize how those *corpuscles* could form stable arrangements (Figure 3).

Metals and their conductivity

About 1900 metals were conceived of as ordered wholes of positive charges through which the 'corpuscles' diffused like the molecules in a gas. Paul Drude (1863-1906) was among the first proponents; he was followed by Hendrik Lorentz. Long ago, for metals, the ratio of the electric to the thermal conductivity, κ/σ, had been found to be a constant, a law called after Wiedemann and Franz (1853). Drude succeeded in deducing that law from the molecular gas model. Where he posited a mean velocity, Lorentz saw a normal distribution in the spirit of Maxwell and Boltzmann (1905). A large amount of generally acknowledged phenomena now made sense in the new light: from the discharge tube phenomena—through the contact potential of bimetals and the Hall effect—to the liberation of *corpuscles* either by heating or by UV-light or X-rays. Thomson was enthused: in his monograph of 1907 he calculated the speed of his *corpuscles* in the metallic 'void' from the mass ratio with the hydrogen atom to be about 100 km.sec^{-1} [4].

▼ **FIG. 3:** Magnetic needles—pushed through small corks—floating on a water surface under the influence of an electromagnet: four needles constitute a square. Five needles would form a pentagon. In case of six needles, one of these is dragged to the center, the other five forming a pentagon (from ref. [4], p.111)



Positive (Canal) rays; their parabolic 'spectral' lines (1912)

Thomson's attention shifted to what he used to call 'positive rays': positive *ions*, that hit the cathode, moving upstream with respect to the *corpuscles*. These rays had been noticed for the first time in the 1880's by Eugen Goldstein (Potsdam); he had called them 'Kanalstrahlen'. The *ions*, too, proved to be sensitive to electric and magnetic fields. However, where the *corpuscles* always showed one and the same trajectory—photographed by Thomson already in 1896—, the *ions* manifested *distinct* paths, which strongly suggested that they varied as to their mass. A whole series of atomic and complex *ions* could be identified in this way, since 1910 by photographic means. In 1912, then, Thomson applied his specialty, viz. the combination of magnetic and electric fields, to a beam of neon ions, which revealed the existence of *two* kinds of equally charged neon *ions*. They were dubbed *isotopes* by Frederick Soddy. It was Thomson's assistant Francis Aston, who, after the Great War, developed the mass-spectrograph and proved him right. It was the time that J.J. was nominated 'master' of Trinity College, in scientific practice Cambridge's most prestigious emeritus status. ■

Acknowledgment

The author is indebted to **Richard Friend**, the actual Cavendish Professor of Physics, and **Malcolm Longair**, formerly Head of the Cavendish Laboratory (1991-2005) for their generous hospitality and to Kelvin Fagan for the especially made photograph of Thomson's tube. **Courtesy photographs:** Cavendish Laboratory, Cambridge.

About the author

Henk Kubbinga is a historian of science at the University of Groningen and member of the EPS History of Physics Group. His work-in-progress concerns *The Collected Papers of Frits Zernike (1888-1966)*, of which volumes I and II are forthcoming (Groningen University Press).

Notes and references

[1] W. Crookes, *Philosophical Transactions* **170** (1879) 135.

[2] It was typically Thomson who, when Everett died in 1933, wrote an obituary of his truefull righthand for well over forty years; see *Nature* **132** (1933) 774

[3] J.J. Thomson, *Philosophical Magazine* **44** (1897) 293

[4] J.J. Thomson, *The corpuscular theory of matter*, London: Constable, 1907

Einstein's witches' sabbath:
the first Solvay council on physics

■ Frits Berends - professor of theoretical physics emeritus, Universiteit Leiden - the Netherlands - DOI: 10.1051/epn/2011502
■ Franklin Lambert - professor of theoretical physics emeritus, Vrije Universiteit Brussel and Solvay Institutes - Belgium

One hundred years ago, on 29 October 1911, a very special event took place in Brussels: the opening of the first Solvay Council, a meeting which would become a milestone in the history of modern physics.

In mid-June 1911, invitations were sent to 23 prominent physicists to take part in a 'Conseil scientifique international'. Its aim was to 'elucidate some actual problems regarding the molecular and kinetic theories'. The confidential letter, signed by Ernest Solvay (1838-1922) – a wealthy Belgian industrialist and scientific philanthropist – stressed that the existing theories could not account for the observed properties of radiation and specific heats. It recalled that Planck and Einstein had shown that the contradictions between theory and experiment could be solved by imposing limitations to the motion of electrons and atoms, an assumption requiring a fundamental revision of current theories. The meeting was said to be convened in the hope that it would pave the way to a solution to the problem. Eight subjects were to be discussed under the chairmanship of Hendrik Antoon Lorentz (1853-1928). The names of the invited members were listed. Replies to the invitation were to be sent to Prof. Dr. W.Nernst in Berlin.

What was so special about this letter?

An *international* conference on physics was most unusual. Only one had taken place before: the 1900 Conference in Paris, with 750 participants from 24 countries, which had been convened by the French Physical Society, not by an international physics organization – as none existed.

Yet, more things were special. Among the invited members only four had been previously informed. The others must have been puzzled. What was so critical in physics? Why this sudden concern? Why Brussels, if no Belgian physicists were involved? What would be the outcome of such a 'summit'? Why was it called by Solvay, and what about Nernst? These questions are still relevant today. This note will try to answer them.

The quantum theory between 1900 and 1910

In spite of its success, Planck's result on black-body radiation in 1900 did not attract much attention. Its derivation remained a matter of discussion between a few experts, including Lorentz. How essential was the assumption that Planck's oscillators could only absorb and emit energy by indivisible 'units' (quanta)?

In 1903, Lorentz showed that the electron theory could only account for the long-wave behaviour of Planck's formula, in accordance with what Rayleigh had deduced from the equipartition theorem - a result also obtained by Jeans and by Einstein in 1905.

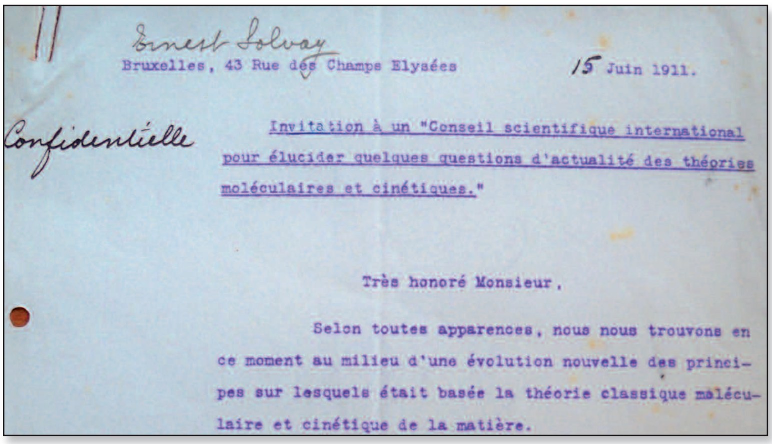
Starting from Wien's radiation formula, which accounted for the short-wave regime, Einstein was led in 1905 to the formulation of his revolutionary concept of 'light quanta', a heuristic view which provided a simple description of the photoelectric effect. In 1907 Einstein applied quantum ideas to matter, treating the oscillating atoms in a solid as Planck-oscillators. He thus obtained a specific heat formula which explained the observed deviations from the classical law of Dulong-Petit.

This was the state of the art in the early quantum theory [1], when the physical-chemist Walther Nernst (1864-1941) entered the field.

Nernst discovers Einstein

Late in 1905 Nernst announced his 'heat theorem', or the 'third law of thermodynamics', a bold proposition with far-reaching implications. It predicted a decrease of specific heats with temperature, and their convergence ►

▼ FIG. 1: Starting lines of Solvay's letter of invitation, reproduced from the one sent to Lorentz, Noord-Hollands Archief, Archive of prof. dr. H.A. Lorentz (1853-1928), 1866-1930, inv.nr. 73.



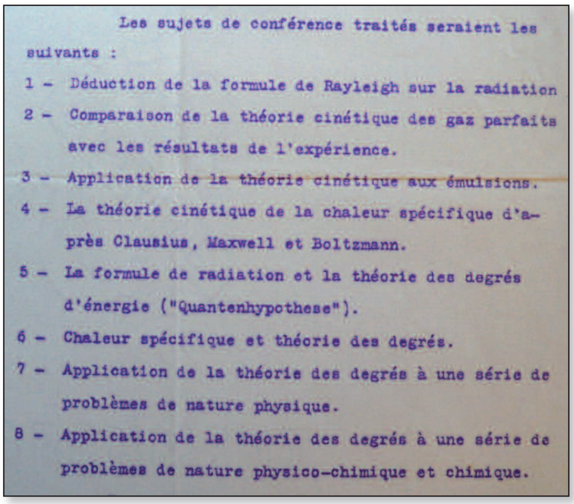
Ernest Solvay
Bruxelles, 43 Rue des Champs Elysées 15 Juin 1911.

Confidentielle

Invitation à un "Conseil scientifique international pour élucider quelques questions d'actualité des théories moléculaires et cinétiques."

Très honoré Monsieur,

Selon toutes apparences, nous nous trouvons en ce moment au milieu d'une évolution nouvelle des principes sur lesquels était basée la théorie classique moléculaire et cinétique de la matière.



Les sujets de conférence traités seraient les suivants :

1 - Déduction de la formule de Rayleigh sur la radiation

2 - Comparaison de la théorie cinétique des gaz parfaits avec les résultats de l'expérience.

3 - Application de la théorie cinétique aux émulsions.

4 - La théorie cinétique de la chaleur spécifique d'après Clausius, Maxwell et Boltzmann.

5 - La formule de radiation et la théorie des degrés d'énergie ("Quantenhypothese").

6 - Chaleur spécifique et théorie des degrés.

7 - Application de la théorie des degrés à une série de problèmes de nature physique.

8 - Application de la théorie des degrés à une série de problèmes de nature physico-chimique et chimique.

▶ **FIG. 2:** Topics for the first Council, as listed in the letter of invitation, NHA, Archive H.A. Lorentz, inv.nr. 73. The corresponding rapporteurs are listed in our text in the order of these eight topics. Experimental topics on black-body radiation covered by Warburg and Rubens are not yet mentioned. The same holds for magnetism, Langevin's topic.

▶ toward the same limit at absolute zero. In order to find evidence for his theorem, Nernst started a programme of specific heat measurements in 1909. Promising results - down to liquid air temperatures - started accumulating in 1910. They agreed qualitatively with the Einstein formula, boosting thereby Nernst's confidence in 'Einstein's quantum theory'.

Early March 1910, Nernst - a major authority in Berlin - decided to pay a visit to Einstein, who was a relatively unknown associate professor in Zürich. Shortly after the meeting, Nernst expressed his enthusiasm in a letter [2] to his Manchester colleague, Arthur Schuster: "It was for me an extremely stimulating and interesting encounter. I believe that , as regards the development of physics, we can be very happy to have such an original young thinker, a 'Boltzmann redivivus'; the same certainty and speed of thought; great boldness in theory, which however cannot harm, since the most intimate contact with experiment is preserved. Einstein's 'quantum hypothesis' is probably among the most remarkable thought constructions ever; if it is correct, then it indicates completely new paths both for the so-called 'physics of the ether' and for molecular theories; is it false, well, then it will remain for all times a 'beautiful memory'". On 1 April Nernst spoke in Paris, about his theorem, the results of his measurements and their agreement with Einstein's formula [3]. Stimulated by his findings and by his foreign contacts, Nernst conceived the idea of organizing a 'Konzil' on quanta, a 'summit', in other words a 'Concile' or 'Conseil'.

▼ **FIG. 3:** Group picture of the second Solvay Council 'Structure de la Matière', in the Solvay Institute of Physiology, october 1913, reproduced with permission of the International Solvay Institutes for Physics and Chemistry, founded by E. Solvay, Brussels.

Nernst's plan for a *Konzil*

Nernst discussed his idea with Planck, Knudsen and Lorentz. They agreed to participate, but Planck preferred to wait one more year for the emergence of new elements that would even increase the crisis. He also expressed concern about the proposed list of participants, indicating that most of them would not be seriously interested in the subject. In spite of this, Nernst decided to go ahead with the help of his Belgian collaborator Goldschmidt, a chemist, an inventor and a personal acquaintance of Solvay.

Early in July 1910 Nernst met the industrialist at Goldschmidt's home in Brussels. Later that month he submitted a detailed proposal for a *Konzil*, asking Solvay to throw it in the waste-paper basket in case of disapproval. The proposal contained a letter of invitation which Solvay only needed to sign.

Nernst also insisted for not being named as the initiator of the project. He was obviously eager to have the quantum theory discussed by internationally recognized authorities, brought together on neutral ground by a fair-minded patron of science. Brussels seemed therefore perfectly suited. Solvay accepted the proposal, but asked for some deferment. Meanwhile, several alterations were made in the list of invited members and in the Council's chairmanship. For instance, Solvay wanted to have a balance between the numbers of German, French and British participants. When Lorentz became the chairman, in May 1911, he arranged for Kamerlingh Onnes to be invited.

Why did Nernst's name show up on the letter of invitation? Quite simply because Goldschmidt left for the Congo, in June 1911, to set up wireless telegraphy, at King Albert's request. The irritated Nernst had no other choice than to take care himself of the correspondence.

The Council in hotel Métropole

Among the 23 invited members, five chose to stand aside: Larmor, Lord Rayleigh, Schuster, Thomson and Van der Waals. Goldschmidt, M.de Broglie and Lindemann, Nernst's British collaborator, acted as secretaries. Opening speeches were delivered by Solvay, Lorentz and Nernst.

11 reports and a letter from Rayleigh were discussed, five on black-body radiation and six on the properties of matter. The rapporteurs were: Lorentz, Knudsen, Perrin, Jeans, Planck, Einstein, Sommerfeld, Nernst, Warburg, Rubens and Langevin. The proceedings appeared in 1912 under the title 'The Theory of Radiation

and the Quanta'. Kamerlingh Onnes's contribution on the discovery of superconductivity was based on what he had said during the discussion of Nernst's report. Rutherford did not mention his remarkable alpha-scattering results, notwithstanding the fact that atomic models were discussed during the reports of Planck and Sommerfeld. The other participants were M.Brillouin, M.Curie, Hasenöhrl, Poincaré and Wien.

The meeting was described by several participants. Einstein joked, in letters [4] to his friends, about the 'witches' sabbath' which would have been a 'delight to diabolic Jesuit fathers'. Brillouin reported [5] on the atmosphere during the long discussions which took place in the overheated little room of hotel Métropole. He described Lorentz' brilliant performance as chairman and translator, who used his wonderful tact and intelligence to intervene whenever a clarification was needed, and who managed to summarize the outcome of the many discussions.

Consequences of the Council

The Brussels meeting was rich in consequences. It made a large group of scientists aware of the importance of quantum problems. One member, Poincaré, produced a proof that Planck's law was bound to introduce an essential quantum discontinuity. This had a decisive influence on Jeans [6]. As he visited Manchester Bohr was told by Rutherford of the Solvay Council discussions [7]. In 1913, he used Planck's quantum of action with success. Louis de Broglie's enthusiasm for quanta was aroused by his reading of the Council's minutes which had been noted by his brother Maurice.

The Solvay Council had also a major impact on Einstein's academic career. His move in 1912 from Prague to the ETH in Zürich was made easier by M.Curie's and Poincaré's strong recommendations, which were sent shortly after the conference. The next step, which brought him to Berlin, as a member of the Prussian Academy, took place in 1913, when the four Berliners from the Solvay Council signed the pivotal election proposal.

Institut international de physique Solvay

The origin of the Council's most remarkable achievement - the founding by Solvay of the International Institute of Physics in May 1912 - was a private meeting on the last day of the conference, at which Solvay, Lorentz and some members discussed experiments for which Solvay would provide the necessary means. Lorentz was asked to work out a plan for an international institute. On 4 January, he presented his concept of the institute. Solvay agreed with it, in principle, and sent one of his co-workers to Leiden to draw up the statutes.

The Institute's main purpose was to stimulate research in physics at an international level, by means of grants. Regular Councils would be organized, and young Belgians would get travelling scholarships. The grants would go to researchers selected by an international committee, chaired by Lorentz. A local committee would take care of the budget, the scholarships and the administration.

Research subsidies were granted until the outbreak of WWI. Among the 40 beneficiaries, six would get a Nobel Prize: von Laue, W. L. Bragg, Barkla, Stark, Franck and Hertz. Moseley, who also obtained support, was nominated in 1915 for the Prize but died on the battle field near Gallipoli.

The war gave rise to a lot of bitterness, and led to the isolation of the Austro-German scientists. In spite of Lorentz' efforts to achieve international reconciliation, it was only in 1926 that experts from all countries could be invited in contrast to the third and fourth Councils. So it was not until the fifth Solvay Council in 1927 that most key-developers of quantum mechanics gathered in Brussels. ■

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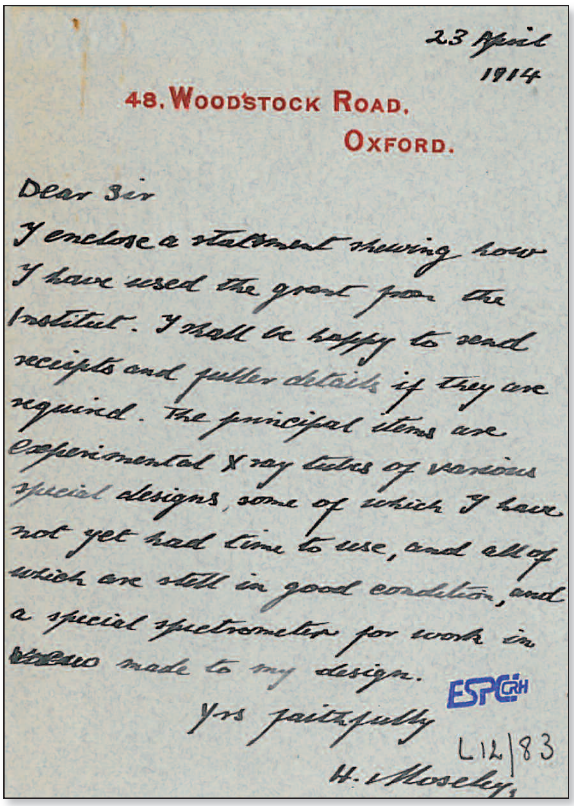


23 April 1914

48. Woodstock Road.
Oxford.

Dear Sir

I enclose a statement shewing how I have used the grant from the Institut. I shall be happy to send receipts and fuller details if they are required. The principal items are experimental X ray tubes of various special designs, some of which I have not yet had time to use, and all of which are still in good condition, and a special spectrometer for work in vacuo made to my design.

Yrs faithfully

H. Moseley

ESPCI CRH

L12/83

◀ **FIG. 4:** Moseley's explanatory note which specifies the spending of his grant, Archive Centre de ressources historiques de l'ESPCI ParisTech, document L12/83.

Ernest Rutherford

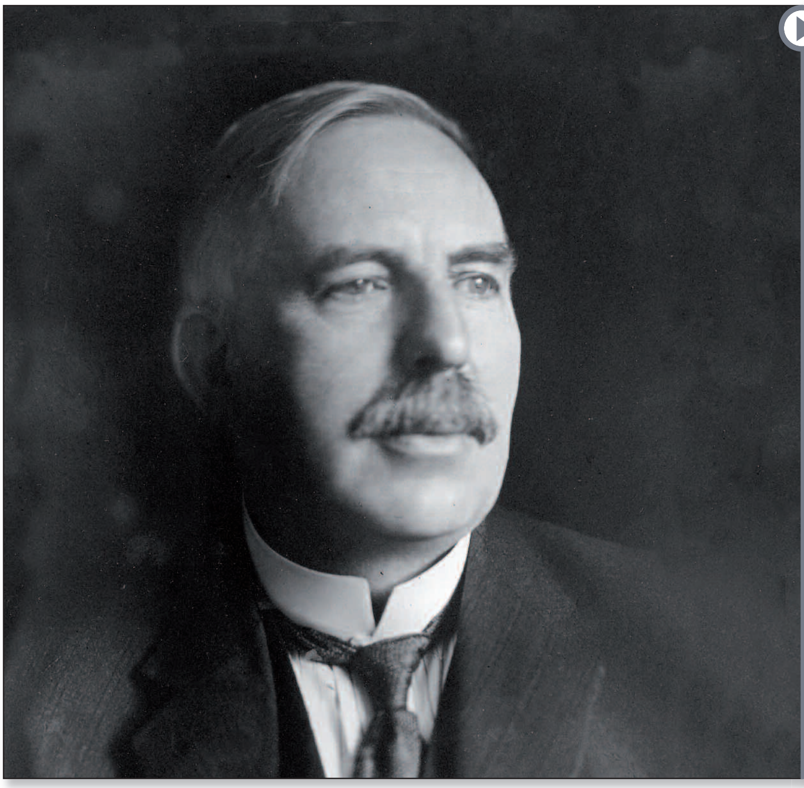
his genius shaped our modern world

■ I.J. Douglas MacGregor - School of Physics and Astronomy, University of Glasgow - UK - DOI: 10.1051/epn/2011503

2011 marks the 100th anniversary of the publication of Rutherford's seminal paper [1] which first identified the atomic nucleus and its essential role in the structure of matter. This crucial discovery marked the birth of nuclear physics and lead to enormous advances in our understanding of nature. Rutherford's legacy has profound and far reaching influences on the shape of the modern world we live in.

Ernest Rutherford was born on 30th August 1871 in Spring Grove, near Nelson, New Zealand. His father, James was a farmer who had emigrated from Perth, Scotland, and his mother, Martha Thomson, was a school teacher from Essex, England. In 1893 Ernest graduated with an M.A. from the University of New Zealand in Wellington and gained a B.Sc. the following year. He was awarded a prestigious "1851 Exhibition Scholarship" to work as a research student at the Cavendish Laboratory, Cambridge, under J. J. Thomson. In 1898 he took up a chair at McGill University, Montreal, where he worked till 1907. He moved back to the UK, to accept the Langworthy Professorship at Manchester University, where he carried out his most famous work. In 1919 he returned to Cambridge as an inspirational leader of the Cavendish Laboratory, building up its reputation as an international centre of scientific excellence. He was awarded the Nobel Prize for chemistry in 1908 and was knighted in 1914. He was president of the Royal Society 1925-30 and became Lord Rutherford (1st Baron of Nelson) in 1931. He died on October 19th 1937 in Cambridge. The radioactive element Rutherfordium (Rf, Z=104) was named in his honour, sixty years after his death.

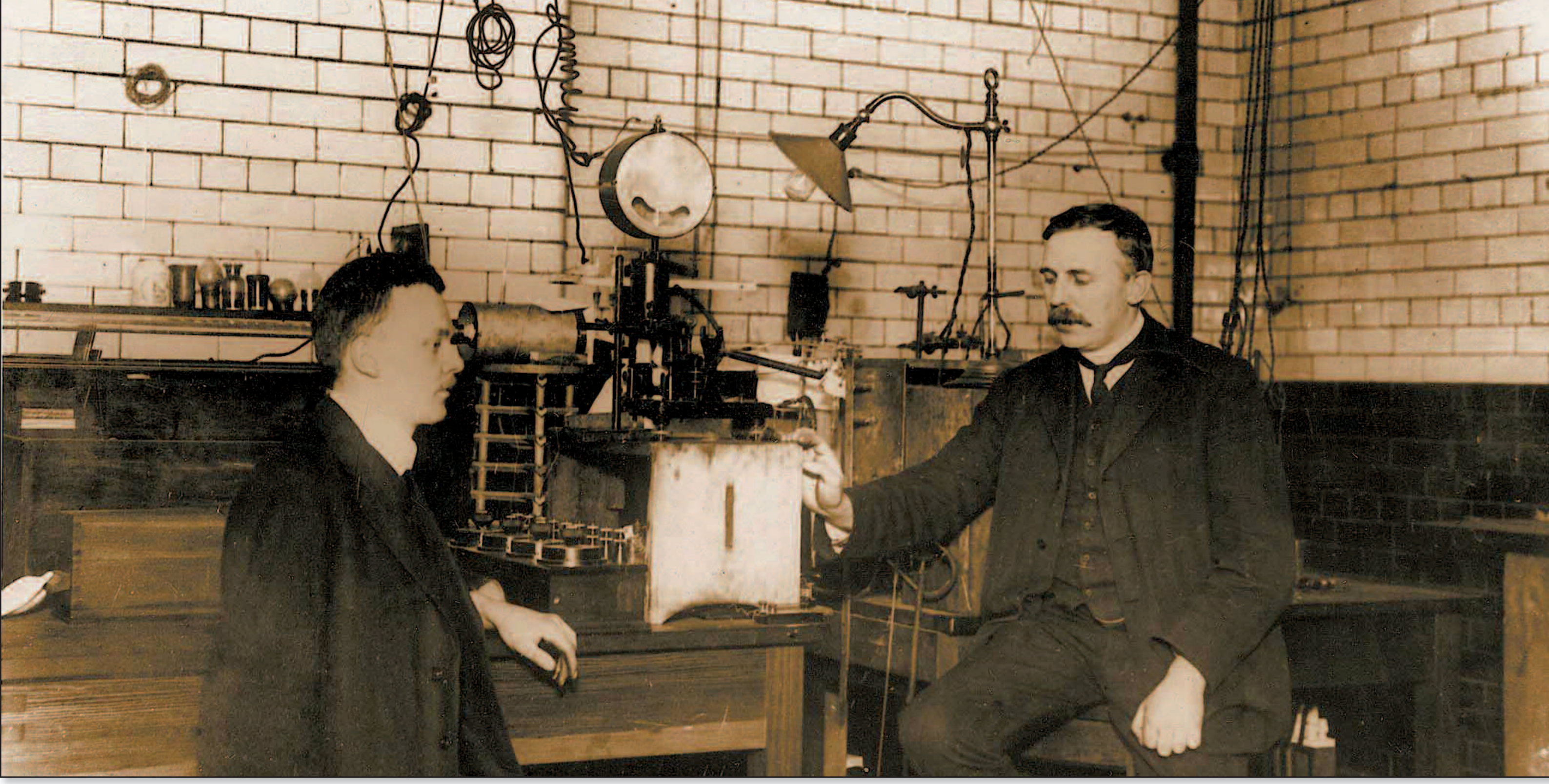
▼ E. Rutherford



Note

This is the first of a series of articles to commemorate the centenary of nuclear physics. This paper describes how Rutherford deduced the existence of a dense, highly charged nucleus at the heart of the atom and outlines the enormous impact his work has had on science and society. This brief account presents only a small selection of his work. Further information is contained in references at the end.

The second article will be a forward-looking discussion of future prospects for nuclear research in Europe, featuring an interview with Prof. G. Rosner, chair of NuPECC (an expert committee of the European Science Foundation) on its new long range plan [2] for Nuclear Physics research. A further article will show how Rutherford's scattering ideas are being applied to experiments at CERN (European Organisation for Nuclear Physics) to study the properties and substructure of nucleons.



▲ FIG. 1: Photograph of Hans Geiger (left) & Ernest Rutherford (right) in their laboratory at Manchester University circa 1908.

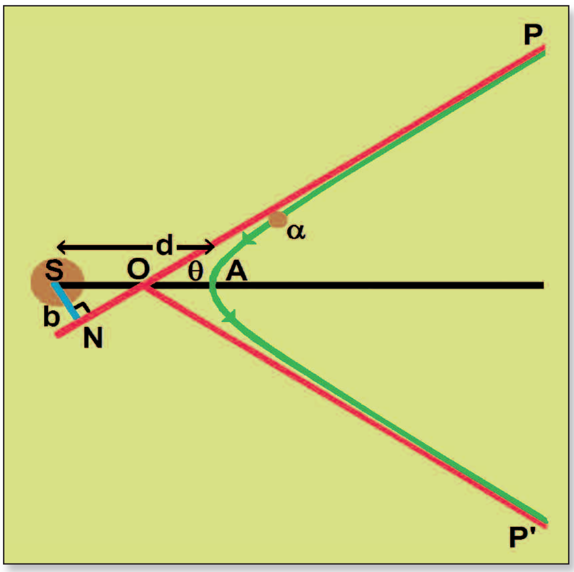
Rutherford's model of the atom

Rutherford published his model of the atom [1] in 1911 as an interpretation of the α-scattering work carried out by Geiger and Marsden [3] two years earlier. The puzzle centred on finding a convincing explanation for the small fraction of α particles (around 1 in 20,000) which were deflected through large angles, after passing through gold foil only 0.00004 cm thick. He argued that the probability of occasional large-angle scatters was inconsistent with multiple small angle scattering, and could only be explained by a single scattering event. This required an "intense electric field" and led him to propose his model of an atom with a charge of $\pm Ne$ at its centre surrounded by a uniformly distributed sphere of the opposite charge.

His arguments did not depend on the charge at the centre, but he chose the correct sign: **"...the main deductions of the theory are independent of whether the central charge is supposed to be positive or negative. For convenience, the sign will be assumed to be positive."** He was aware that there were unanswered questions about how such a structure could exist: **"The question of the stability of the atom proposed need not be considered at this stage…"** These questions were only fully answered much later.

Using a reasonable estimate for the nuclear charge he calculated the distance of closest approach (~34 fm) for a typical head-on α particle to be completely stopped and provided the first ever order-of-magnitude estimate of the size of the nucleus. He showed that the trajectory taken by an α particle was hyperbolic and related the angle of deviation δ to the perpendicular distance b between the line of approach and the centre of the nucleus. He showed the scattering probability was proportional to $\mathrm{cosec}^4(\delta/2)$ and inversely proportional to the 4th power of velocity. An important test of his model was to calculate the dependence of the relative number of scattered particles n on the atomic weight A. The ratio $n/A^{2/3}$ should be constant. The measured values for eight elements between Al and Pb ranged from 208 to 250 with an average of 233. He concluded: **"Considering the difficulty of the experiments, the agreement between theory and experiment is reasonably good."**

Following the publication of his ground-breaking paper [1], Rutherford worked closely with other leading physicists of the day. Niels Bohr visited Manchester in 1912 and again 1914-16. Bohr's model of stationary non-radiating electron orbits [4] added credence to Rutherford's atom and answered the question of why the electrons do not fall into the nuclear core. Subsequent developments in the theory of quantum mechanics gave this an even sounder footing. However, understanding the small size and strong binding of the nucleus would have to wait till the 1930s, when the neutron was discovered and Yukawa first described the strong attractive force binding neutrons and protons together in terms of meson exchange.



◀ FIG. 2: The α particle, experiencing an inverse square repulsive force, follows a hyperbolic trajectory (green) as it approaches the nucleus located at S, the external focus of the hyperbola. It enters along the asymptotic direction PO (red) reaching its closest approach d=SA at the apse of the hyperbola before exiting along the second asymptote OP'. The angle of deviation δ=π-2θ depends on the energy of the alpha particle and its impact parameter b=SN.

While Rutherford carried out (α,p) reactions, changing the elemental composition of the target, the term "splitting the atom" is more usually associated with nuclear fission. In 1934 Fermi carried out experiments bombarding Uranium with neutrons. The results of this early work were not clear. However in 1938 Hahn and Strassmann reported detecting Barium in the products of similar experiments. This was subsequently interpreted by Meitner and Frisch as nuclear fission. The extraction of large amounts of energy from the fission process required the development of a chain reaction process. This was researched during the second world war and resulted in the production of nuclear weapons. Later, in 1951, electricity was generated from a nuclear reactor and the phrase "atoms for peace" gained wide currency.
These world-changing facets of nuclear physics were not developed until after Rutherford's death. However, Al-Khalili [5] has discussed whether Rutherford was aware of the possibilities. In the early 1930's Rutherford said "**anyone who expects a source of power from the transformation of these atoms is talking moonshine**". Certainly this is true for a single reaction. It requires a chain reaction to transform the scenario. Al-Khalili notes that Rutherford took a close interest in the work of Fermi and Bohr and reports some comments he made which confirm Rutherford was aware of the possibilities of extracting energy from atoms.

▼ TABLE 1: Nobel Prizes for work in atomic structure, nuclear physics, quantum physics or fields which have developed out of nuclear physics. Physics Prizes are in grey and Chemistry prizes in blue.

Year	Recipient	Year	Recipient
1901	W. Röntgen	1954	M. Born & W. Bothe
1902	H. Lorentz & P. Zeeman	1955	W. Lamb & P. Kusch
1903	H. Becquerel, P. Curie & M. Curie	1957	C. Yang & T-D. Lee
1908	E. Rutherford	1958	P. Cherenkov, I. Frank & I. Tamm
1911	M. Curie	1959	E. Segrè & O. Chamberlain
1917	C. Barkla	1960	D. Glaser
1918	M. Planck	1961	R. Hofstadter & R. Mössbauer
1921	A. Einstein	1963	E. Wigner, M. Goeppert-Mayer & H. Jensen
1921	F. Soddy	1964	C. Townes, N. Basov & A. Prokhorov
1922	N. Bohr	1965	S-I. Tomonaga, J. Schwinger & R. Feynman
1922	F. Aston	1967	H. Bethe
1927	A. Compton & C. Wilson	1968	L. Alvarez
1929	L. de Broglie	1969	M. Gell-Mann
1932	W. Heisenberg	1975	B. Mottelson & J. Rainwater
1933	E. Schrödinger & P. Dirac	1976	B. Richter & S. Ting
1934	H. Urey	1979	A. Salam & S. Weinberg
1935	J. Chadwick	1980	J. Cronin & V. Fitch
1935	F. Joliot-Curie & I. Joliot-Curie	1983	S. Chandrasekhar & W. Fowler
1936	V. Hess & C. Anderson	1984	C. Rubbia & S. van der Meer
1938	E. Fermi	1988	L. Lederman, M. Schwartz & J. Steinberger
1939	E. Lawrence	1990	J. Friedman, H. Kendall & R. Taylor
1943	O. Stern	1991	R. Ernst
1944	I. Rabi	1992	G. Charpak
1944	O. Hahn	1994	B. Brockhouse & C. Shull
1945	W. Pauli	1995	M. Perl & F. Reines
1948	P. Blackett	1999	G. 't Hooft & M. Veltman
1949	H. Yukawa	2002	R. Davis, Jr., M. Koshiba & R. Giacconi
1950	C. Powell	2004	D. Gross, D. Politzer & F. Wilczek
1951	J. Cockroft & E. Walton	2008	Y. Nambu, M. Kobayashi & T. Maskawa
1952	F. Bloch & E. Purcell		

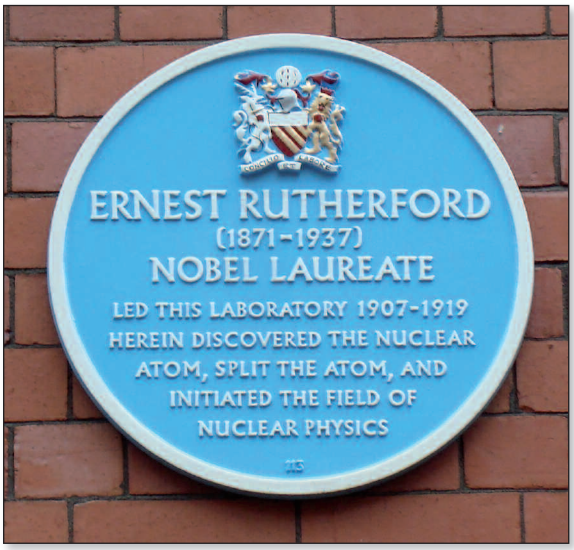
Nobel Prizes

Nobel prizes are the ultimate accolade for scientific discovery. Atomic structure lies at the boundary between Physics and Chemistry and prizes in both subject areas have been awarded for atomic and nuclear research. It is somewhat surprising that **Ernest Rutherford did not receive a Nobel Prize for his work on the structure of atoms**. He did, however, receive the 1908 Nobel Prize for Chemistry [6]. This was in recognition of his earlier work into the disintegration of the elements and the chemistry of radioactive substances.
However, the true importance of Rutherford's contribution can be gauged by the fact that 8 Nobel Prizes in Chemistry and over 50 in Physics have been awarded for work directly related to atomic structure, nuclear physics, quantum physics and other fields which have developed from nuclear physics (see table 1).
Rutherford worked closely with many of the leading scientific brains of the early 20th century (J.J. Thomson, R.B. Owens, F. Soddy, O. Hahn, H. Geiger, E. Marsden, N. Bohr, H.G. Moseley, G. de Hevesy, A. Szalay, J. Chadwick, P. Blackett, J. Cockroft, R. Walton, G.P. Thomson, E.V. Appleton, C. Powell, F.W. Aston, C.D. Ellis and others). This close interaction played an important part in the rapid development of physics during and after his lifetime. It is reported in [6] that he played an influential role at the Cavendish "steering numerous future Nobel Prize winners towards their great achievements". It is clear that Rutherford was present at the heart of a very large number of fundamental scientific discoveries.

Rutherford's legacy

Rutherford's work provided the key to an exciting new world of science and applications. The physics of the atom is governed by the rules of quantum physics, taking us into domains classical physics cannot predict or describe. This has produced a step change in our understanding of nature and a host of previously unimagined applications. As studies advanced our understanding of atoms, chemical elements, radioactivity and isotopes has been transformed.
Milestones in the development of nuclear science included the discovery of the neutron, the positron and antimatter. The field of particle physics was spawned as a separate research discipline. Energy production

in stars and the creation of light and heavy elements in stellar processes rely on nuclear reactions. Direct applications such as medical imaging have transformed the diagnosis of disease and radiotherapy has advanced the treatment of cancer. Detector and accelerator technologies have found wide application in industry. The fields of solid state physics, electronics, computing and modern optics all depend on quantum physics which was initially developed to explain phenomena in nuclear and atomic systems. The Institute of Physics (IOP) has commissioned a report "Nuclear physics and technology – inside the atom" [7] which details the impact on society of research into the atomic nucleus. There is scarcely an area of modern physics which does not owe a debt of gratitude to Ernest Rutherford.



◄ **FIG. 3:** Blue Plaque at Manchester University commemorating the achievements of Ernest Rutherford.

Celebrations of Rutherford's Achievement

Many events have been organised to celebrate the centenary of Rutherford's famous publication[1] .The EPS Nuclear Physics Division has commissioned a website [8] to collate information on this notable anniversary.

A reception, bringing together politicians and scientists, was held in the House of Commons on 29th March 2011. The reception was hosted by E. Vaizey M.P., whose constituency includes the Rutherford Appleton Laboratory, and sponsored by the New Zealand High Commission, the IOP, and the UK STFC Research Council. Ernest Rutherford's family was represented by his great granddaughter, Prof. M. Fowler. Speakers from science (Prof. B. Cox), the IOP (Dr. B. Taylor), politics (E. Vaizey M.P.) and diplomacy (D. Leask, the New Zealand High Commissioner) highlighted the sheer genius of Rutherford in unlocking the structure of the atom. At the event the STFC announced the creation of the Ernest Rutherford Fellowship Scheme to support early-career researchers in the UK [9].

On 5th April 2011 Al-Khalili gave a highly acclaimed public lecture [5] on "Nuclear Physics since Rutherford" at the IOP Nuclear and Particle Physics Divisional Conference, in Glasgow. This conference brought together many separate scientific disciplines which owe their origins to Rutherford's work. The Rutherford Appleton Laboratory, which takes its name from the two scientific pioneers, Ernest Rutherford and Edward Appleton, organised a Schools meeting on 19th May 2011, where Al-Khalili was again the guest speaker.

The main celebration was the Rutherford Centennial Conference [10] (Manchester, 8—12 August 2011). This brought the commemorations back to the city where Ernest Rutherford carried out his pioneering work. The conference highlighted the anniversary with talks by leading international speakers on a wide range of topics which have developed out of Rutherford's work.■

Acknowledgments

The author is grateful to Profs. **S. Freeman**, **J. Al-Khalili** and **M. Fowler** for information about the life and work of Ernest Rutherford. Photographs are provided courtesy of the University of Manchester and Barry (Bazzadarambler) who posts on flickr®.

About the author

Douglas MacGregor is a reader in Nuclear Physics at the University of Glasgow. He serves on the Rutherford Centennial Conference organising committee, is secretary of the EPS Nuclear Physics Division and chairs the IOP Nuclear and Particle Physics Division.

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Jan Czochralski, the pioneer of crystal research

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Not only was Jan Czochralski the first to propose a method of pulling metallic single crystals from a melt, and to successfully quantify their growth rates, he passionately devoted his entire productive life to crystal research, material science and chemistry, to name only a few areas of his expertise [1].

▲ Frozen Baltic See water, with some crystals and close-packed configuration

Jan Czochralski (1885-1953) was born in Kcynia near Bydgoszcz (Kujawy and Pomorze district in Poland), roughly halfway between Warsaw and Berlin. His seminal work on metallic single crystals and their growth rates was published in *Zeitschrift für physikalische Chemie*, received for publication in August 1916, but not published until two years later [2]. This paper was an example - rarely seen these days - of being precise and specific in presenting research achievements. In just three pages the author reported on his new findings, namely, that a method of pulling metallic single crystals had been discovered in terms of their growth rates (and nucleation-promoting ionic additives), and that it had been applied for testing crystal growth of three metals: *Sn*, *Pb*, and *Zn*. This raised, in fact, great admiration both in Poland and abroad [1,3-5]. As a consequence of this work, he is still recognized as one of the founders of today's crystal-growth technology and research [3], although originally his method was rather elaborated for the three metals mentioned above.

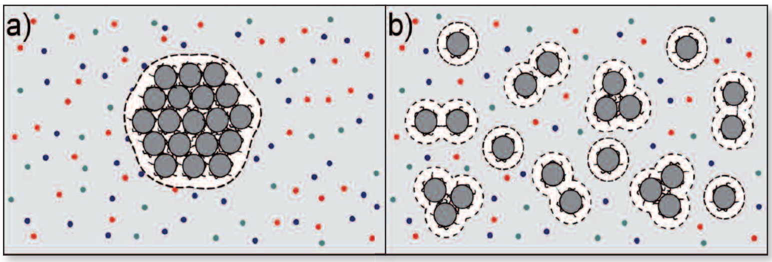
Crystal growth

While performing research on crystal growth and its theroretical foundations, I was often surprised by Czochralski's quite unexpected interests and connotations in many, not entirely technological, aspects of crystal growth. They were mostly addressed in terms of solid-state type (poly)crystalline forms [3], see Figs. 1 and 2. His interests involved not only initial single-crystal growth but also the emergence of "nonequilibrium" polycrystals, as well as their recrystallization [1-3]. As one may know, both kinds of processes are based on one-seed and many-seeds nucleation and growth-phase transformation rules [5]. However, they rely on different competition behaviour of the feeding material, coming either from a solution or from some melt [4,5]. The basic difference concerning an (un)even distribution of the feeding material is illustrated schematically in Figs. 1a and 1b. These figures also illustrate possible differences in output morphologies, depending on the material-involving competitive nuclei. This results ultimately in crystalline polymorphic forms [6].
Which of the present-time developments are, in my personal opinion, the most important ones when seen in the context of Czochralski's well-known [1-5] accomplishments? It seems to me that there are at least two: (i) The solid-liquid complex crystal-interface dynamics, in general characteristic of (non)linear morphological instabilities and primarily resulting from concerted actions of mass- and thermal diffusion fields [6]; (ii)

Crystal growth of colloid and (bio)macromolecular non-Kossel type systems. These are complex structures, with serveral crystallizing large molecules per unit cell in non-equivalent positions [7], see Fig. 2.

Crystal-liquid interface

Concerning point (i), it has been proposed to solve this analytically and numerically in terms of the Stefan moving-boundary (diffusion) problem. This describes a diffusive mass and/or heat transport accross a crystal-liquid (originally: ice-water) interface [8]. Many attempts have been made since the early 1960s to achieve a robust nonlinear extension of the morphological, though originally linear, crystal-involving (in)stability analysis by Mullins and Sekerka (MS) [4,5]. The MS problem was originally treated as being driven either by a concentration gradient or by undercooling [5]. The result of the instability analysis of the growth process has been a square-root-of-time evolution of the sphere radius, as well as an exponential time decay of its crystal-surface perturbation amplitude [4]. However, none of the attempts were able to reproduce an accepted universal and robust solution to the problem of crystal-phase advancement into its ambient (solution/melt) phase, irrespective of the fact that the phenomenon had always been proposed to be diffusion-controlled [4]. Very recently, it has become clear that, for instance, (bio)macromolecular crystal formations cannot follow exclusively the diffusion-limited path. In fact, experimental evidence shows quite often a constant growth rate [5]. This requires a model of mass- or molecular-aggregates-involving incorporation in versatile near-crystal-surface stable conditions. Such a model, while based on minimal entropy-production rate [7], is also benchmarked by the complex problem of interface-controlled growth. The resulting growth rate is often analogous to the MS instability modus to a reasonable extent [4,5]. A careful analysis of such interfacial stochastic dynamics may inevitably lead to (non)equilibrium, mature-stage conditions of the cessation-to-growth. These conditions state that a crystal is formed upon some prevailing, temporary but algebraic velocity-time correlations, pointing to a flicker (*i.e.*, quenched) noise, residing in the interfacial zone. Otherwise, a disorderly scenario, pointing to uncorrelated (thermal) noise, prevails over its order-promoting and fairly self-organising counterpart [7].

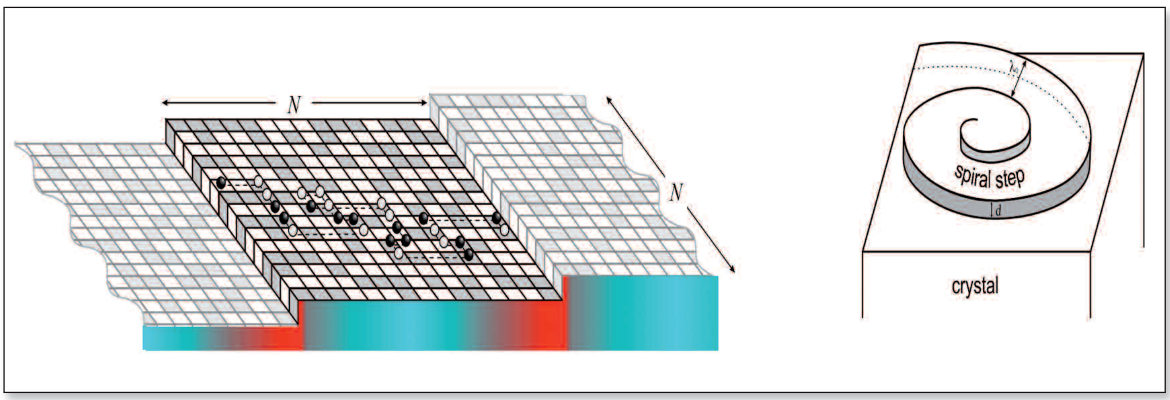


▲ **FIG. 1:** Schematics of a single "hexagonal" crystal growth for two cases. Panel a): The crystal welcomes the addition of atoms, ions or molecules which are depicted as point-like, coloured (incoming) objects. They represent, for example, different (macro)ionic species incorporated in a crystal-growth form when emerging from a solution of elecrolytic nature [6]. Panel b) represents quite the same case (be it immature and non-hexagonal) but now involving many randomly distributed nuclei that steadily try to compete for the coloured point-like (macro)ionic material, thus depleting the adjacent (white) regions. The shaded background represents an aqueous solution, whereas the coloured point-like objects are protein macroions (blue), and ionic precipitants, such as those coming typically from *NaCl* dissociation (in red and green, respectively), which serve to facilitate the nucleation. If the incorporation is successful, the built-in soft material becomes eventually dark and is drawn towards the round, grey objects [7]. (Courtesy of J. Siodmiak, Bydgoszcz.)

Colloid and (bio)macromolecular systems

Concerning point (ii): It would have been a dream of Czochralski to have the privilege of tackling such problems (see pp. 47-66 by A.A. Chernov in [5]), including utilisation of colloid stability (e.g., in late W.A. Tiller's works [5]). Why? First, in order to verify his expectation that biomolecules, such as lysozymes [6-7], would form single non-Kossel crystals of many polymorphic forms [6]. Second, to show that there exists a certain, though limited, structural order in their morphologies [5]. ►

▼ **FIG. 2:** Cartoon of a single terrace of a model spiral-grown crystal (see drawing on the right) of width N ~ λ_0 onto which two different types of virtual constituents of the crystal are shown: hydrophobic (white balls) and hydrophilic polar (dark balls). They perform both translational and rotational random motions, preferentially along the blue-coloured terrace's interior, but stay between the red kinks, equipped with temperature-agitated Ehrlich-Schwöbel barriers [4-7]. The spiral growth illustrated on the right is often referred to as the Burton-Cabrera-Frank (BCF) mode.
(Courtesy of J. Siodmiak, Bydgoszcz; see also http://arxiv.org/abs/1103.4551.)



▲ FIG. 3: Middle-aged Jan Czochralski, patiently writing down his research notes. (Courtesy of Z. Czochralska, Kcynia.)

► Third, to prove that the principal model of dislocation-driven BCF growth [5-7] is useful for performing at least computer simulations designed for soft-matter crystal formation (see [6-7], and references therein). Next, that the cumbersome problem of crystal-interface involvement can be treated as being separated into working schemes of practical interest, especially the ones concerning the so-called crystal-growth layer [9] or active interfacial zone [5]. In this field, the future undoubtedly belongs to computer simulations, judiciously supported by powerful physical concepts such as those of thermodynamic-kinetic nonequilibrium and mesoscopic nature [7]. Proposals which are based on experimentally well-motivated scenarios and the ones correctly addressing the involving fields' interplay are worth entering. Especially those proposals will deserve special attention which follow the intermingled thermal and electrostatic, as well as hydrophobic pathways of the involved spatio-temporal competing fields that are located within the interface [9]. Protein databases, such as the *PDB* [6], will immensely support this way for crystallizing new protein and colloid species.

It should be concluded that future progress in this field would be impossible without including both Czochralski and his CZ method [1,3,5] in our worldwide technical-knowledge accumulating database [1,5,9]. This is especially worth mentioning in the year in which almost a century has passed since he decided to submit his practical and incredibly useful results, which established the experimental foundations for the new age of silicon-based high technology [1,2,3,5,8]. Each of us greatly benefits, directly or indirectly, from his inheritance. Therefore, it seems right to recognize his valuable work, and once again recall abbreviations such as *CZ*, tightly accompanied by the others, namely, BCF and/or MS [5].

Czochralski and World War II

Czochralski's political attitude during World War II was sometimes questioned, especially since he conducted research in an institute of Warsaw University of Technology (WUT) founded by German occupants. However, the doubts formerly expressed about this in [1,3] must be radically changed due to the revelation of some important facts. A thorough investigation of the Polish state archives [10], covering personal political activities of those times, rediscovered him as a person who cooperated tightly with the Polish Underground State Army (the so-called *Armia Krajowa*). In fact, he made this military organization aware of some German technical facilities, which were hidden near Warsaw and somewhere abroad. Based on this very recent finding [10], the Senat of WUT rehabilitated him ultimately as WUT professor on its meeting on June 29, 2011. Thus, after 66 years [1,4] of reputation loss as a Polish university professor, who seemed to have collaborated with Germany during World War II, this supposition has very likely been refuted [10]. ■

Acknowledgement

My deepest thanks go to Dr. Teresa Saskowska (Sniadecki Hospital in Znin) for drawing my attention to Ref. [10].

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■ Herman C.W. Beijerinck - Eindhoven University of Technology - DOI: 10.1051/epn/2011505

The unbearable lightness of teaching…

Just listen to the President of the university and hear what you don't want to hear *again*. "Our university is research-driven, we are among the best on the 'bla-bla' list, and, of course, next year we will be even better." What has happened to the university as the honorable place where you become a 'homo universalis', well trained in abstract reasoning, in the art of scientific research, out-of-the-box thinking and eloquence to convey ideas to society?

Which of the two is more important, the output of well-trained people – M.Sc., PhD, post-doc, P.D.Eng. - or the number of publications in refereed journals? Just listen to the talk of the town: research dominates everyday life. Writing grant proposals burns many hours of a professor's life. In contrast, keeping track of his 'extended family' engaged in 'real life' jobs in industry, banking, policy making or teaching has low priority.

At university, the Hirsch index is the yardstick for excellence. One has a Hirsch index equal to H when H of one's papers is cited in literature at least H times. A successful career ends at H=20 to 25; the giants end up with an H-value in the range of 40 to 50. But why don't we have an index for our educational impact? Are we ashamed of this aspect of a university career?

The Feynman index

We have to decide where the major impact of our work lies. Is it in research, where most of our 150 papers lose their impact after a couple of years? Or is it in the 150 to 200 members of our 'extended family', who have settled down in their careers outside university? Their success depends on the academic quality of their education – both in content and in personal skills. Their impact goes on for 35 to 40 years, in turn influencing other people. A well-educated 'homo universalis' has an impact that goes far beyond a brilliant scientific paper in a renowned journal. I argue that we cannot go on without an index for educational impact. To honor a great educator in the field of physics, I propose to call it the Feynman index.

Of course, research is very important for a university. It is the major tool for educating our students. But the phrasing of the president should read: "We are a center of excellence for teaching at an academic level, and yes, we are highly successful in acquiring the best tools for this education by cutting-edge research, and yes, our alumni end up in society in those jobs where they are on the crossroads of new developments, and yes, they are making the decisions that count for our future."

My proposal is to define an educational index based on the number of people directly influenced by our 'extended family'. To obtain a Feynman index equal to F, at least this number of one's former students runs a group with at least F employees. The nature of the group is unimportant. The dissemination of knowledge *and* professional approach is what counts. Educational impact is thus measured by successful careers of our offspring.

The Feynman index forces universities to keep track of their alumni: not only for some serious PR-boasting, but for real feedback. The extra effort may seem useless, but the same has happened in the field of tracking citations: a careful analysis of scientific output has helped to improve the quality of university. Detailed knowledge of the performance of our alumni will provide valuable feedback to university. It is time to make a change: introducing the Feynman index can be of major help. ■

The moon as a detector of Ultra-High-Energy neutrinos

■ Olaf Scholten - KVI, University of Groningen - Groningen, The Netherlands - DOI: 10.1051/epn/2011506

When ultra-high-energy (UHE) particles impact on the lunar surface they initiate a particle cascade. The sizeable negative charge excess will cause emission of coherent radio waves, making these impacts detectable on Earth with sensitive radio telescopes. Using the Westerbork Synthesis Radio Telescope array we searched for these impacts to uncover UHE particle origins.

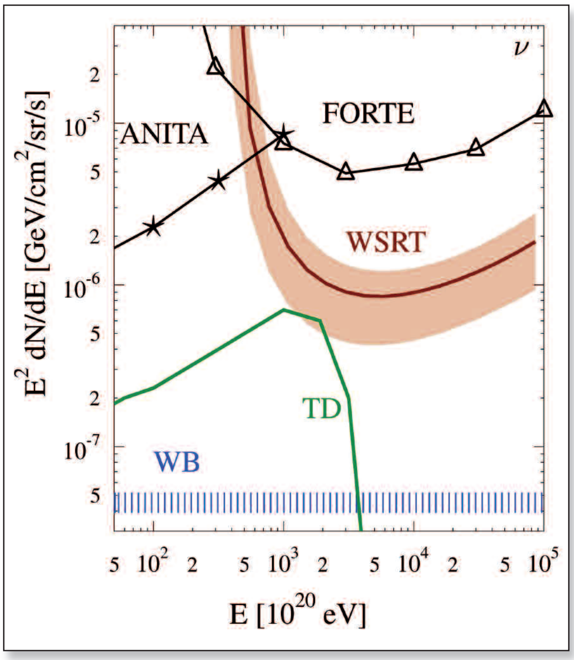
Cosmic rays and neutrinos at ultra-high energies are the messengers of the most energetic processes in the universe. The particles have energies well in excess of 10^{20} eV, far above energies that are reachable at CERN and almost equal to the kinetic energy of 1 kg falling from a height of 2 m. At energies E below 0.5×10^{20} eV their flux [1] falls roughly as $E^{-2.7}$. It is generally assumed that the particles are accelerated to these extreme energies by the so-called Fermi acceleration mechanism, where the average particle energy increases by repeated interactions with a shock wave [2]. This mechanism produces a power-law spectrum as is observed. In alternative top-down models, the high energy particles result from the decay of massive particles that are relics from the Big Bang.

The UHE sources of origin are not known, although close to 20% of the UHE particles seem to come from the direction of Centaurus A [3]. This is a bright radio galaxy in the southern hemisphere constellation Centaurus, emitting copious amounts of synchrotron radiation. At a distance of only 11 million light-years it is the closest such galaxy. A major challenge in finding the sources of origin is the very small observed flux, of the order of a single particle per 100 km^2 per year for energies in excess of 10^{20} eV. At higher energies the flux of cosmic rays falls with energy even faster than $E^{-2.7}$, perhaps because of the so-called GZK effect. Greisen, Zatsepin and Kuzmin predict that, at sufficiently high energies, cosmic-ray protons interact with the photons in the Cosmic Microwave background. In that process other particles are produced, such as neutrinos, that carry an appreciable fraction of the original energy. The flux of energetic cosmic rays decreases as a result. Since neutrinos interact exclusively via the weak interaction they can propagate over cosmological distances. Neutrinos are also expected to be produced at the sources of cosmic rays. Either way, neutrinos point back to the original cosmic rays. For this reason we have set out to detect UHE neutrinos, which requires very large and efficient detectors. One particular approach which we describe here is to determine UHE particle fluxes through the detection of coherent radio waves which are emitted when an UHE particle interacts with the lunar surface.

Cherenkov radiation

In a dielectric, the propagation speed of electromagnetic waves is reduced by a factor equal to the index of refraction. A charge moving at light-speed through such a dielectric will emit Cherenkov radiation, a process which is similar to the emission of sound waves (the sonic boom) when an aeroplane exceeds the velocity of sound. An UHE particle, neutrino as well as cosmic ray, with an energy of 10^{18} eV that interacts with the surface layer of the Moon (the regolith) will generate a cascade of particles, which may contain 10^8 particles (mostly electrons and positrons) all moving with velocities close to the speed of light in vacuum. The number of particles scales linearly with the initial energy. Due to processes such as Compton scattering and positron collisions off electrons bound to the atoms of the regolith, a net excess of electrons is formed in the shower front. This excess is typically equal to about a third of the number of particles in the shower. Because of the large energies involved, all particles stay close together and can be envisioned as a large charged cloud moving at a velocity close to the speed of light, with a typical dimension of 10 cm. This moving charge will thus emit Cherenkov radiation. At wavelengths exceeding 10 cm (frequency less than 3 GHz) the individual charges cannot be distinguished and the emitted radiation is coherent. The emitted power is proportional to the square of the number of particles in the cascade. Evidence for coherent radiation from the charge excess [4] has recently been observed [5] as radio emission from cosmic-ray-induced air showers at the Pierre Auger Observatory in the Argentinian pampas. At sufficiently high energies, the emitted pulse on the Moon is strong enough to be detectable with radio telescopes on Earth. With a visible area of 10^7 km^2, the Moon can be used as a highly efficient detector for UHE particles since the lunar surface layer, the regolith, consists of dust and small rocks and is very transparent to radio waves. The regolith has been created in a constant bombardment by meteorites. In some places it has a thickness of several kilometres. A number of experiments have been performed looking for radiation at frequencies around 2 GHz where the intensity is expected to reach its maximum [6]. At these frequencies the ►

◄ the moon during a lunar eclipse © iStockPhoto



▶ **FIG. 1:** Two model calculations for the flux of UHE neutrinos vs. their energy are compared with the limits derived from the WSRT, FORTE, and ANITA observations (see text). For a neutrino flux exceeding the indicated limits one should have detected at least a single event with 90% confidence.

emitted radiation is sharply focused at the Cherenkov angle since the distance over which the shower travels, about 3 m, is much larger than the wavelength, 15 cm at 2GHz.

At lower frequencies the angular spread of the emitted radiation increases to a maximum at frequencies of 100-200 MHz where the wavelength is comparable to the longitudinal extent of the shower. At even lower frequencies there is only a marginal increase in angular spread while the intensity of the emitted radiation drops linearly with frequency. The increase of the angular spread of the radio emission is important for two reasons. First, the radiation created will be detectable on Earth for many more angles of incidence. Second, for a shower parallel to the lunar surface the Cherenkov emission angle is the same as the angle of total internal reflection at the surface. Thus, only the UHE particles impinging at the rim of the Moon in the direction towards the Earth will emit a detectable signal at high frequencies. At lower frequencies, the particles impinging anywhere in any direction on the lunar surface may emit detectable signals. Because of the large attenuation length, radio waves created at large depths (as much as 500 m is very well possible) may also result in a detectable signal at Earth, which makes for a very large detection volume. These effects combined result in a detection efficiency that increases with about the third power of the wavelength [7].

Cosmic rays interact directly at the lunar surface because of their rather large interaction cross section. They convert their entire energy into a particle cascade, called the hadronic shower, in the uppermost layer of the regolith. UHE neutrinos, on the other hand, may traverse many kilometres of rock before they interact, and in the interaction about 20% of their energy is converted into a hadronic shower, while the remaining energy is carried off by a single lepton.

In both cases – cosmic rays and UHE neutrinos – coherent Cherenkov radiation will be emitted by the many particles in the hadronic shower. In this article we will limit ourselves to neutrino detection.

Observations

We have observed the Moon with the Westerbork Synthesis Radio Telescope (WSRT) in the frequency range of 115—180 MHz with full polarization sensitivity. These observations have produced the most stringent flux limit yet at the highest energies [8]. The observations were made using eleven equally-spaced WSRT parabolic antennas of 25 m diameter. Our particular set-up created two simultaneous beams aimed at different sides of the Moon. This allowed us to implement an anti-coincidence condition since a lunar Cherenkov pulse should be visible in only one of them.

To analyse the data from the WSRT observations, we did not follow the usual procedure in astronomy where one determines the intensity at a particular well defined frequency, which requires signal integration over appreciable time-scales. In the present case we are instead interested in pulses that have a very short, nanosecond, structure which requires a large bandwidth in frequency. In this wide band, terrestrial communication frequencies need to be filtered out. A further complication is the dispersion of radio signals by the ionosphere of the Earth. In the analysis, we corrected for this frequency-dependent delay by using the ionospheric information obtained from GPS data.

In the off-line analysis the data are 'cleaned' further by eliminating pulses that are very wide, and pulses that appear in both beams in the same time trace. By simulations, we found that there was no pulse from the Moon with a strength exceeding 120 times that of the Galactic noise level in 125 nanoseconds. This non-detection in a time span of 47.6 h converts into a limit on the flux of neutrinos, where attenuation of the signal in the Moon, transmission at the lunar surface, and angle with respect to the direction of the neutrino have to be taken into account. The resulting 90% confidence flux limit is shown in figure 1 by the curve labeled WSRT. The band around the curve shows the possible error of the determined flux limit, mostly due to uncertainties in the attenuation of radio waves in the regolith.

To place the observations in context, they are compared with those by the FORTE satellite [9], observing the Greenland ice cap for radio flashes coming from neutrino interactions in the ice cap, and from the ANITA balloon mission where the Antarctic ice cap is searched for radio flashes [10]. The Figure gives also two model predictions. Waxman and Bahcall (WB) derived an estimate of the flux of neutrinos based on the observed flux of UHE cosmic rays assuming a generic model for neutrino production at the production sites of the cosmic rays [11]. In Top-Down (TD) models UHE neutrinos are created from the decay of super massive relics ($M_x=10^{24}$ eV is used in the figure) formed at the time of the Big Bang. The new data from Westerbork allows for setting much a tighter limit on the flux of UHE neutrinos which is just touching the predicted flux of a TD model.

Recent developments

LOFAR (Low Frequency Array) is a new-concept radio telescope presently being completed in The Netherlands and surrounding countries. LOFAR combines thousands of simple wire dipole antennas. In software-manipulation, the relative phasing of the antennas is tuned such that the array can be pointed towards any direction in the sky. Because such software pointing does not require any physical antenna movement, multiple beams may be observed simultaneously. The large collecting area benefits the signal-to-noise ratio. The multi-beam option allows for the formation of a sufficient number of beams to cover the entire lunar surface. The long baselines make the position resolution on the Moon very precise which improves the sensitivity to localized pulses as generated by neutrino impacts.

With the much higher sensitivity of LOFAR weaker pulses and hence neutrinos at lower energies can be detected than was possible with the WSRT. In Figure 2, we give the flux limit that is reached in a week of observation with LOFAR. This limit implies that we will detect a dozen events if the flux of neutrinos is of the magnitude estimated by Waxman and Bahcall. This is very exciting as it would constitute the first detection of UHE neutrinos. In the Figure we also give an estimate for the neutrino flux due to the GZK effect but this is rather model-dependent [12].

Outlook

Already advanced plans exist for a successor to LOFAR, called the Square Kilometre Array (SKA). The SKA will be built using the same aperture-array concept as LOFAR where many simple antennas are coupled through software to effectively simulate a gigantic single-dish antenna. SKA will have a collecting area of about 1 km^2 which is much larger than that of LOFAR. A larger collecting area allows for the detection of fainter objects. For lunar pulse observations it is also important that the full frequency range of interest is covered. It ranges from 100 MHz, corresponding to a wavelength comparable to the longitudinal extent of the shower, up to a few GHz, corresponding to a wavelength comparable to the size of the moving charge cloud.

Such increases in collecting area and receiver bandwidth allow us to detect neutrinos created in the interaction of UHE protons with the Cosmic Microwave Background as well as the signals caused by the impacts of cosmic rays on the lunar surface with energies as low as 10^{20} eV. The sensitivity for cosmic ray detection will be such that we will collect the same number of counts in a single week as in a few years of operation of the Pierre Auger Observatory. ■

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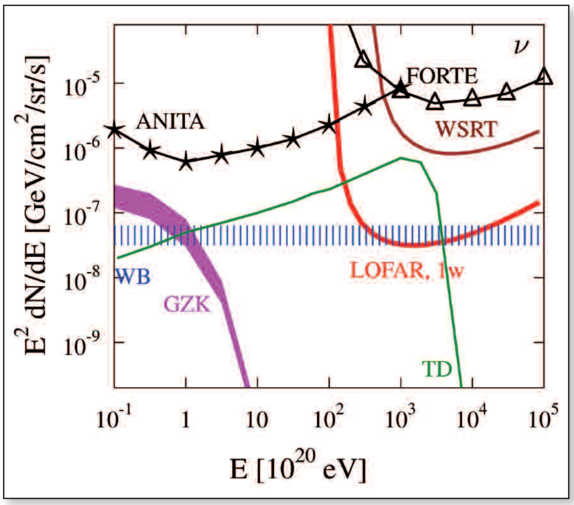

◀ **FIG. 2:** The predicted sensitivity for LOFAR is compared with the results obtained from the NuMoon observations with WSRT.

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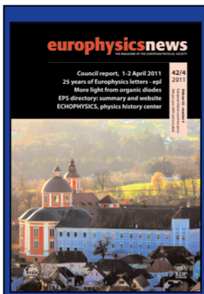

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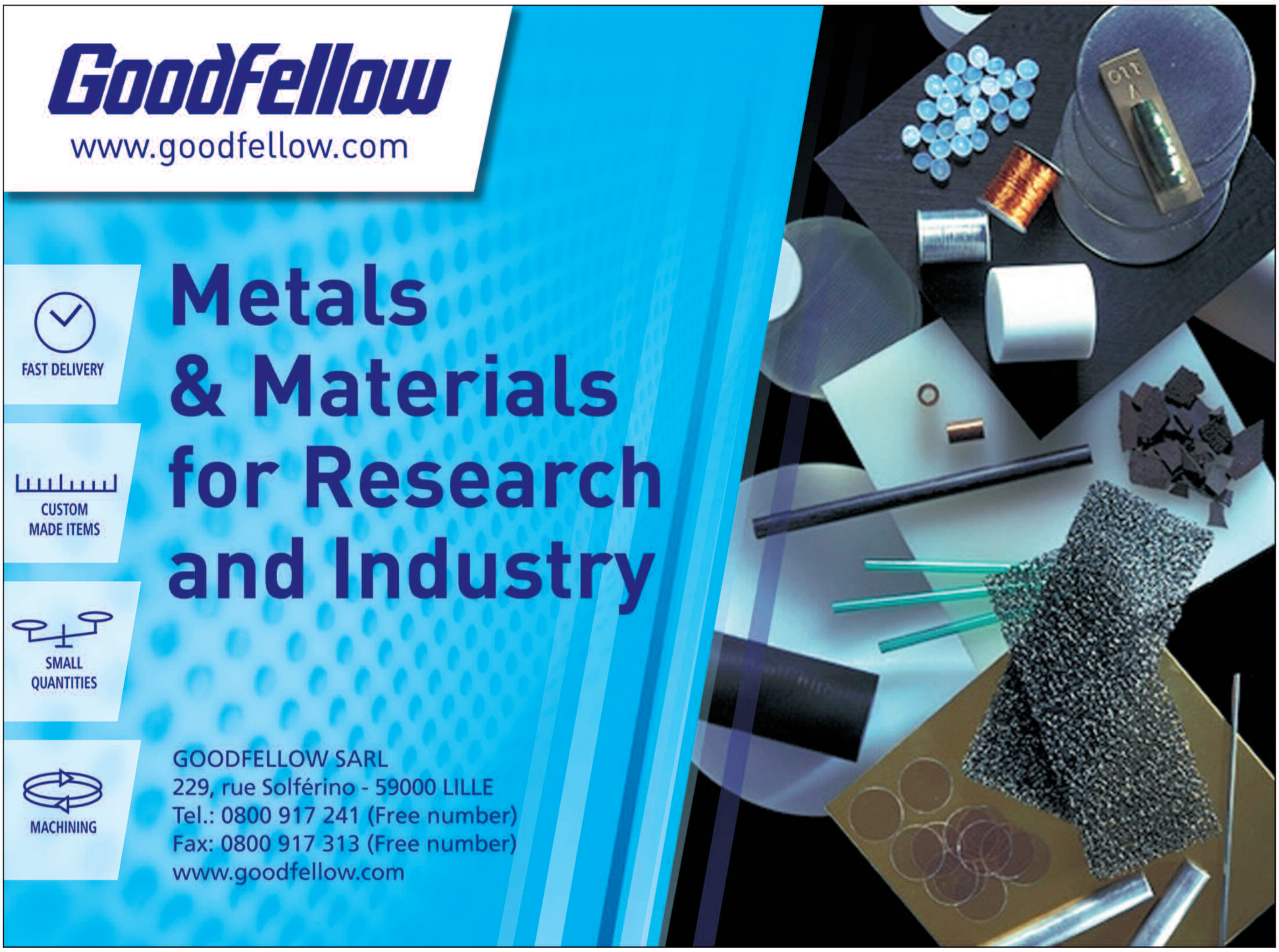
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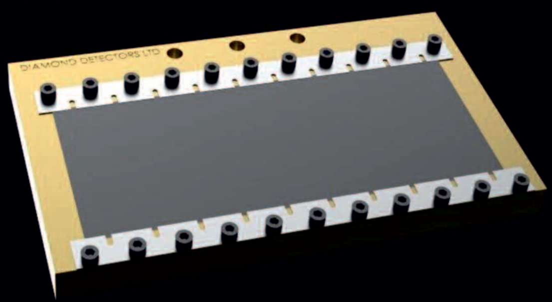
Radiation detectors employed in beam lines for synchrotrons, colliders and cyclotrons.

Also used for tissue equivalent medical X-ray and charged particle therapy.

Applications for CVD Diamond

- Beam positioning & diagnostics
- Radiotherapy, particles and x-ray
- Fluorescence Screens & Windows
- Radiation-hard tracking (sLHC)
- Energy Resolutions
- Heavy Ion
- Neutron & α detection

New for 2011



Quadrant beam position monitor

The low-Z single crystal diamond detector is mounted on either a conventional PCB or on a diamond carrier substrate for high thermal loads.

Diamond Fluorescence Screens, Windows & Absorbers

Windows, absorbers and two grades of diamond Fluorescence materials FL and OP.

Diamond Detectors Ltd are exhibiting at the conferences below

2nd International Particle Accelerator Conference (IPAC´11), San Sebastian, Sept 4 - 9

http://www.ipac-2011.org/inicio.asp?apt=8&sub=15

13th International Conference on Accelerator and Large Experimental Physics Control Systems, Grenoble, Oct 10 - 14th

http://icalepcs2011.esrf.eu/

2011 IEEE Nuclear Science Symposium and Medical Imaging Conference, Valencia, Oct 23rd - 29th

http://www.nss-mic.org/2011/NSSMain.asp

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For users familiar with Lorentz, the flow of the program is now quite intuitive with many new options readily available.

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Send us your model, whatever the level of complexity. **We will show you how to get results from your exact design** – no canned demos.

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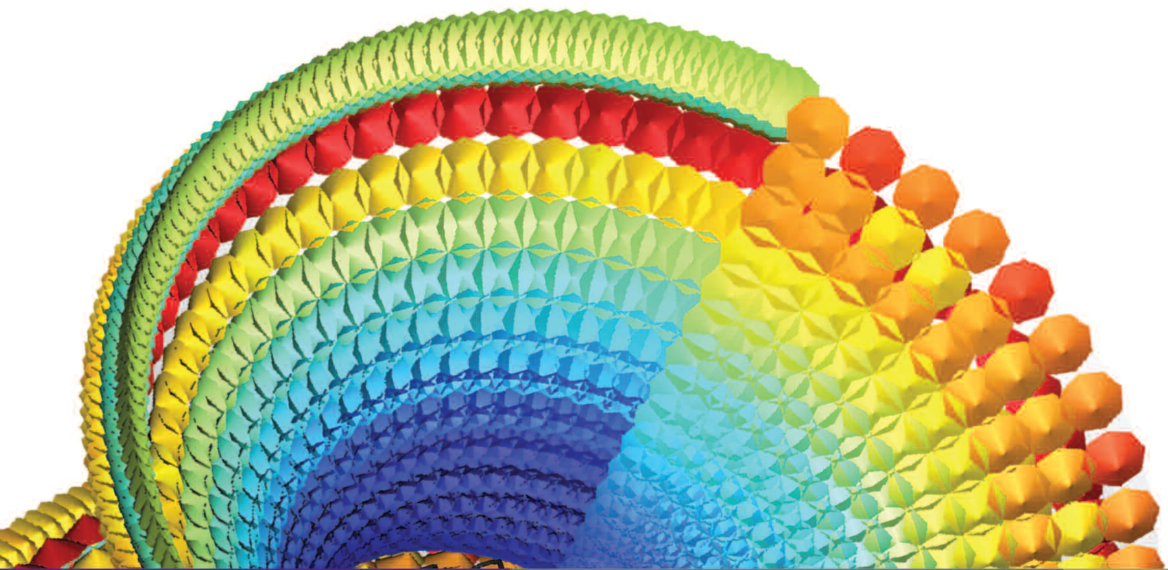
ANALYZE AND MODEL:

- BEAMS
- IONS
- CHARGED PARTICLES
- BEAM OPTICS
- ELECTRON GUNS

BEM & FEM available in the same package



LORENTZ v9.0

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